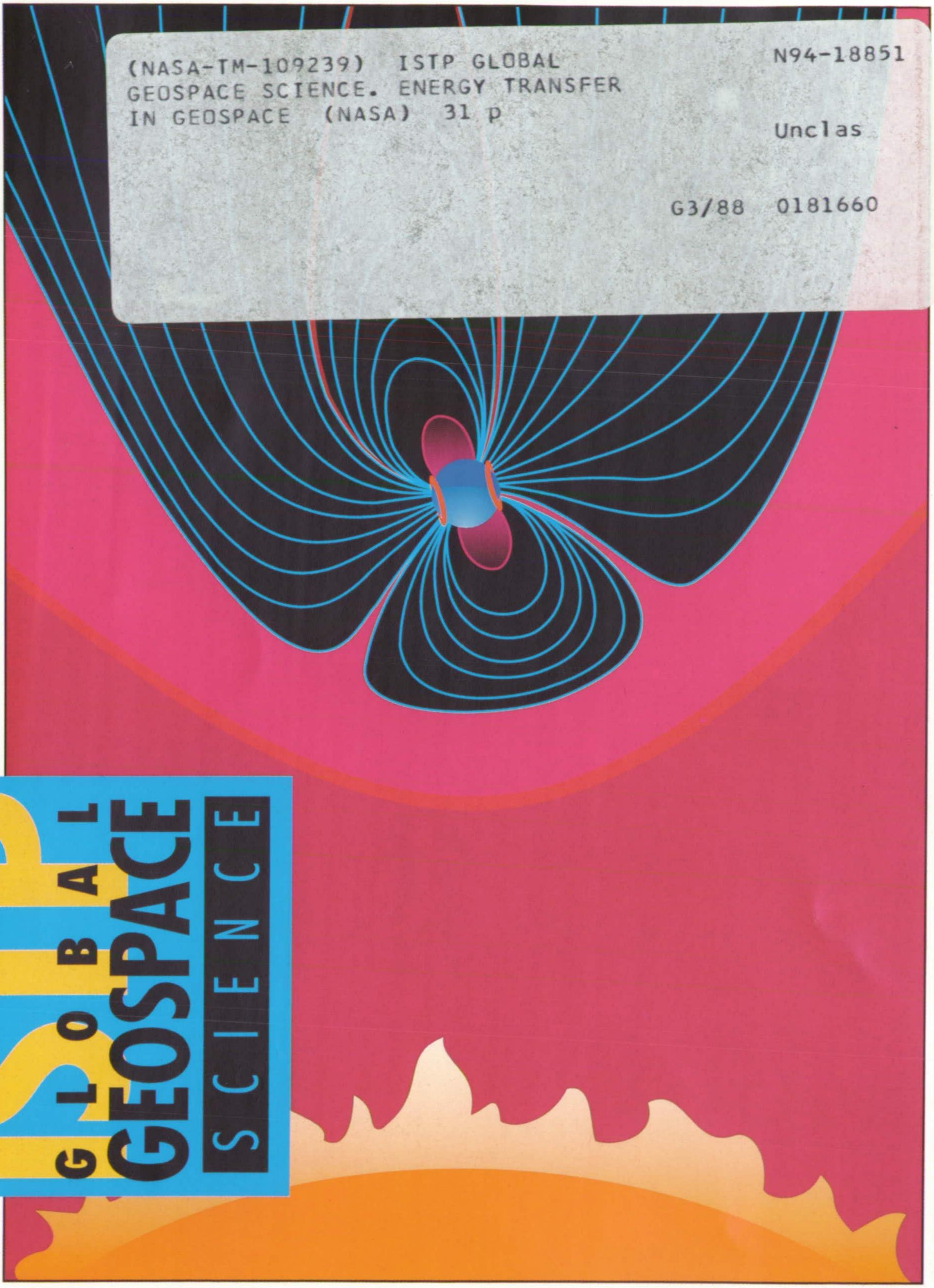

ISTP

GLOBAL GEOSPACE SCIENCE

ENERGY TRANSFER IN GEOSPACE

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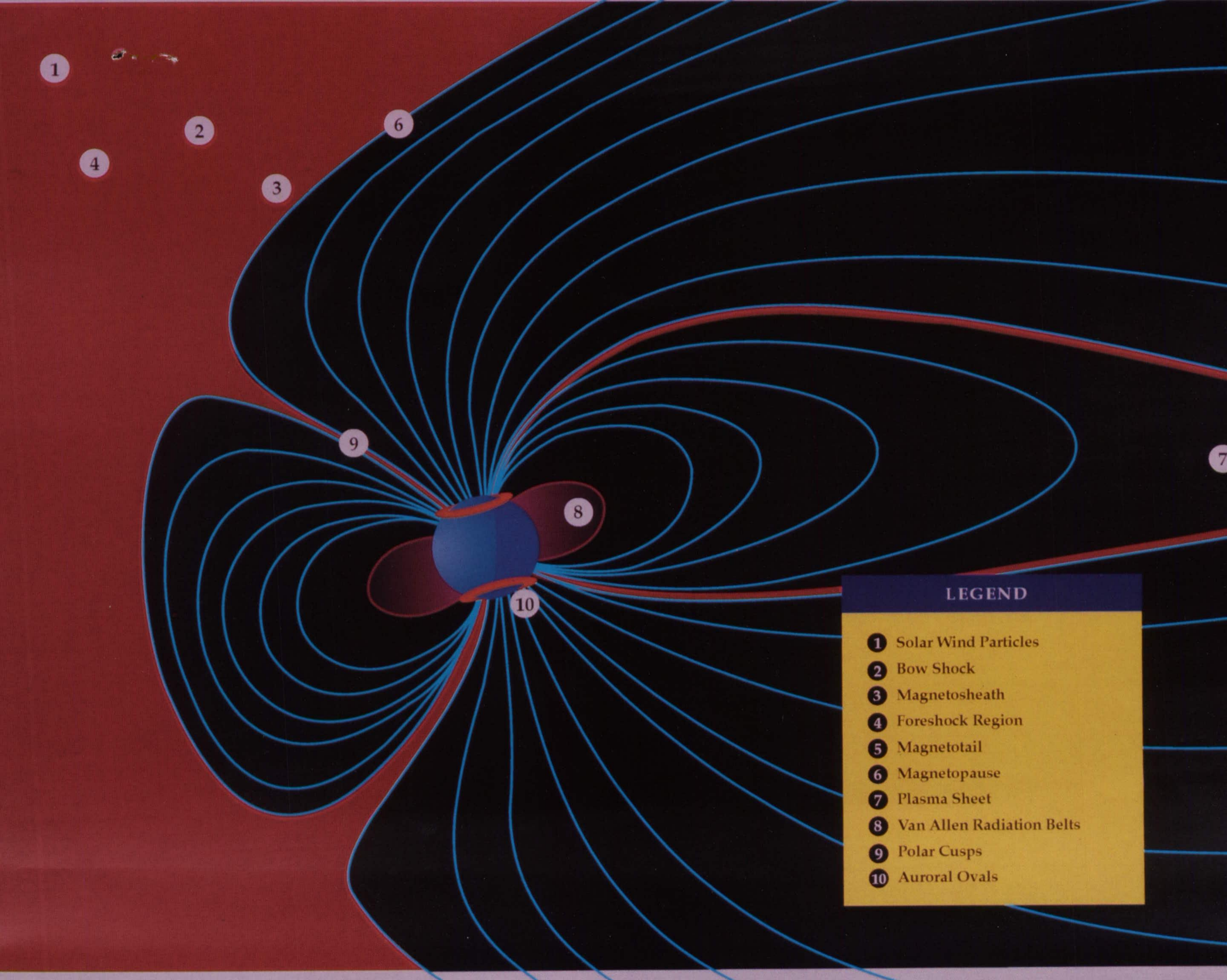
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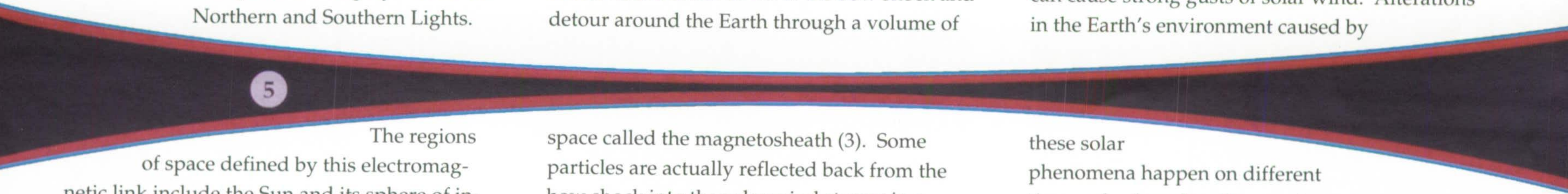
LEGEND
1 Solar Wind Particles
2 Bow Shock
3 Magnetosheath
4 Foreshock Region
5 Magnetotail
6 Magnetopause
7 Plasma Sheet
8 Van Allen Radiation Belts
9 Polar Cusps
10 Auroral Ovals

In ancient times, rituals of the winter solstice summoned the victory of light over darkness so that spring could return again. Mankind has always known that life on Earth is dependent on light and heat from the Sun, but beyond our senses, electromagnetic forces also link the Sun and the Earth in a dynamic interplay that generates and characterizes our protective near-Earth environment and sparks the displays called the Northern and Southern Lights.



The regions of space defined by this electromagnetic link include the Sun and its sphere of influence—the heliosphere—and the Earth and its much smaller sphere of influence—geospace. Geospace includes the near-Earth space and reaches toward the Sun, where the Sun's heliosphere is disturbed by Earth's magnetic field.

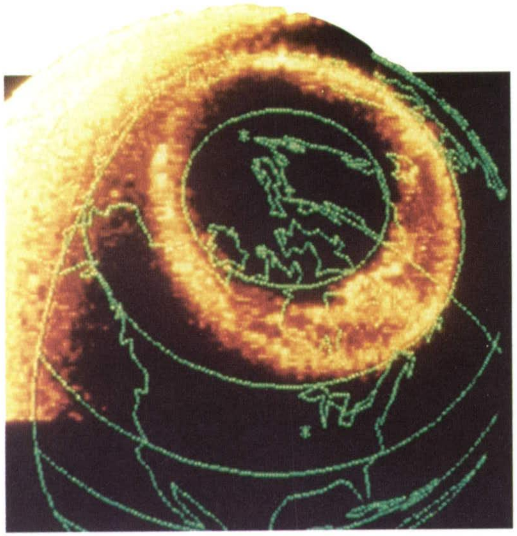
Energy streams out from the Sun toward the Earth in the form of a solar wind of electrified particles (1). This hot, ionized gas, called a plasma, streams toward Earth at a million miles per hour, carrying particles and magnetic fields from the Sun outward past the planets. Earth is shielded from the full blast of these particles by its magnetosphere, the region around the Earth dominated by the Earth's magnetic field.

As the solar wind approaches the Earth's magnetic field, a highly supersonic shock wave is created sunward of the Earth, similar in shape to the shock wave created when a jet plane breaks the sound barrier but much stronger. This shock wave is called the bow shock (2). Most of the solar wind particles are heated and slowed down at the bow shock and detour around the Earth through a volume of space called the magnetosheath (3). Some particles are actually reflected back from the bow shock into the solar wind stream in a region of turbulence called the foreshock (4).

As the solar wind flows around the Earth, it stretches the Earth's magnetosphere out into a long tail, the magnetotail (5). Some of the particles being carried past the Earth leak through the barrier at the boundary of the Earth's magnetic field, called the magnetopause (6), and are trapped inside the magnetosphere and stored in the plasma sheet (7) and Van Allen radiation belts (8). Some particles rush through funnel-like openings at the poles, called the polar cusps (9). Some energetic particles come down magnetic field lines and enter into Earth's upper atmosphere. Particles accelerated in the magnetotail excite atoms and molecules in the Earth's atmosphere. These atoms and molecules then emit light known as the Northern and Southern Lights (or auroras) in the auroral ovals (10), giving a visible signature of this energy transfer from the Sun to the Earth.

The Sun is an active star whose variability affects the flow of the solar wind. For example, solar-flare explosions, associated with sunspots, can cause strong gusts of solar wind. Alterations in the Earth's environment caused by these solar phenomena happen on different time scales from less than a minute to over a century. The Sun's variations (for example, solar x-ray bursts) can affect specific regions on Earth within the time required for light to travel from the Sun to the Earth (8 minutes). Longer timescale, global solar variations may affect long-term climatic changes.

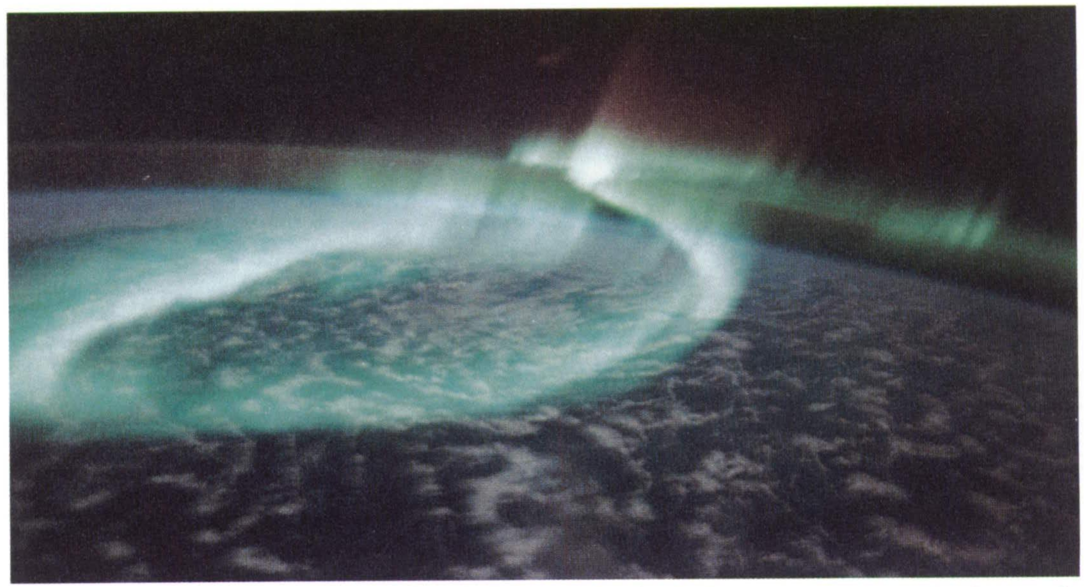
The best known terrestrial effects of solar activity are the geomagnetic storms and auroras that occur within a few days following major solar flares. In turn, the auroras contribute to the heating and ionizing of the upper atmosphere that generate the ionosphere, located 100 miles above the Earth, where the neutral atmosphere gives way to ionized plasma.



At higher latitudes, such as in Sweden, people can see auroras almost every night, but people at lower latitudes see them only during especially strong magnetic storms. The aurora crowns the globe in light. This ultraviolet image of the aurora encircling the North Pole was made by the NASA spacecraft Dynamics Explorer 1. The photograph shows the sunlit hemisphere in the upper left and a fainter airglow near the Equator.

Above our atmosphere, ions and charged particles bounce along and spiral around magnetic field lines, deflected from direct impact on the atmosphere and the people below. Thus, the geomagnetic field forms a mantle protecting us from harmful cosmic radiation. To understand how life on Earth has evolved through these and other influences, we need to understand their balance in the Sun-Earth system.

Events on the Sun can trigger changes in the electrical and chemical properties of the atmosphere, the ionosphere, the magnetosphere, the ozone layer, and high-altitude temperatures and wind patterns. These changes cause magnetic storms, communications static, power blackouts, and navigation problems for ships and airplanes with magnetic compasses. Also, satellites and spacecraft can be damaged or can reenter Earth's atmosphere prematurely because of solar storms. The ability to anticipate particle outbursts and fluctuations in the plasma flowing from the Sun and in the magnetic field due to solar activity will be increasingly useful as more of our science, commerce, and national security depend on the operation of vehicles in space.



This view of the aurora Australis, or Southern Lights, was taken by the Discovery spacecraft. The photograph shows a band of airglow (extending from the middle to the right side), whose existence is attributable to atomic oxygen, at an altitude of 80 to 120 kilometers above the Earth. This type of airglow is most intense at latitudes of about 65 degrees north and south and in the spring and fall of the year. Other atoms, such as molecular nitrogen, can also contribute to airglows.

Solar-terrestrial physics concerns the study of the generation, flow, and dissipation of mass, momentum, and energy between the Sun and the Earth. Mass, momentum, and energy are carried by charged particles that compose the solar wind. When the solar wind reaches the Earth, some solar-wind particles enter the magnetosphere; this coupling between the solar wind and the Earth means that the solar wind can influence the Earth's upper atmosphere.

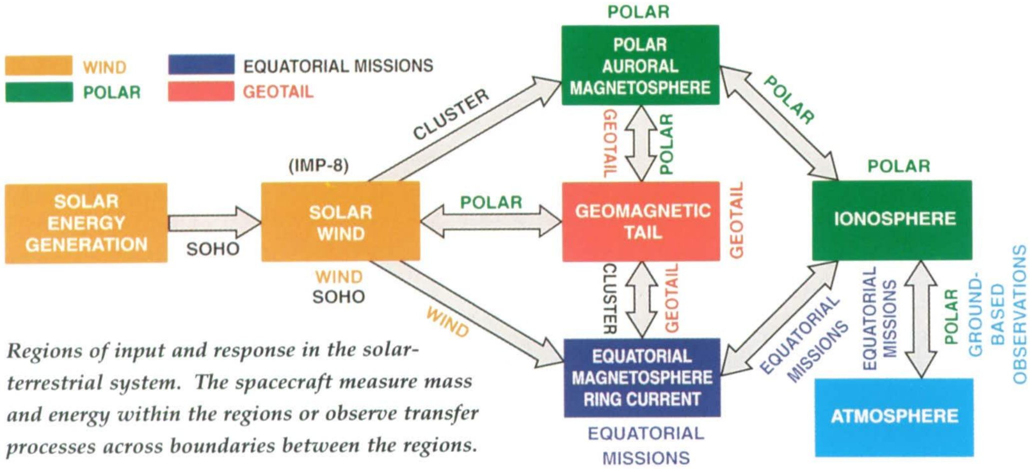
As the first step in addressing the behavior of this solar-terrestrial system, the Global Geospace Science (GGS) Initiative will use the Wind and Polar satellites, provided by the National Aeronautics and Space Administration (NASA), and the Geotail satellite, provided by the Japanese Institute of Space and Astronautical Science (ISAS), to perform simultaneous and closely coordinated measurements of the key geospace regions and will add data from equatorial missions. These equatorial missions include two series of spacecraft: the Geosynchronous Operational Environmental Satellite (GOES) Program of the National Oceanic and Atmospheric Administration (NOAA) and the Los Alamos National Laboratory (LANL) spacecraft from the Department of Energy (DOE). These satellites will monitor magnetic-field and particle changes that occur when particles are energized during auroral events. Additional data from other existing satellites such as NASA's International Magnetosphere Physics satellite (IMP-8) will be used to supplement these observations.

The intention behind the GGS Initiative is to understand the physical mechanisms and various regions controlling the transport of mass, momentum, and energy in geospace. In understanding the magnetosphere, the regions within it can be compared to cellular structures separated by thin transition or boundary regions. The bulk of the mass, momentum, and energy resides in the large-volume cells. However, the driving physical processes occur in the interaction regions between these cells. The GGS Initiative satellites will provide essential knowledge of these small-scale processes and their importance in deter-mining the characteristic behavior of the magnetosphere.

The approach to understanding these physical mechanisms is to compare the simultaneous measurements taken by the GGS Initiative spacecraft in different regions, ground-based measurements that provide a time history of disturbances, and theoretical studies and modeling to understand the physics that underlie the system. This three-pronged approach draws upon the talents of scientists throughout the space physics community and related disciplines and optimizes the scientific return of the program.

The multiple spacecraft are set up to watch the cause and effect of events at the Sun that trickle down, ultimately, into Earth's atmosphere. As shown in the diagram on the next page, the solar wind interactively transfers mass, momentum, and energy into the system as a whole through the polar auroral regions, the magnetotail, and the ring currents. Energy is coupled back and forth between these regions and the solar wind and between these regions and the ionosphere. Ultimately, a portion of the mass and energy from the Sun is transferred into the atmosphere, heating and energizing it. The spacecraft either measure mass and energy within the regions themselves (illustrated by the spacecraft names over a region's box) or observe transfer processes across boundaries (indicated by names next to process arrows).

One of the great strengths of the GGS Initiative lies in its capability to permit major orbital changes for certain spacecraft, allowing study of the global behavior of the geospace system, not from one specific combination of several satellite orbit configurations but from many combinations. Ultimately, Wind will be stationed in the solar wind upstream from the Earth to observe the input of energetic magnetospheric particles and their escape back into



Regions of input and response in the solar-terrestrial system. The spacecraft measure mass and energy within the regions or observe transfer processes across boundaries between the regions.

the solar wind. Polar will measure the flow of plasma to and from the ionosphere on auroral magnetic field lines and will observe the deposition of particle energy into the ionosphere and upper atmosphere. Equatorial missions will observe and sample the buildup of particles in the Van Allen radiation belts. Geotail will provide extensive simultaneous measurements of entry, storage, acceleration, and transport in the geomagnetic tail. It will sample the inflation and collapse of the magnetotail: what controls it and how coupling occurs between the solar wind input and the Earth's fields.

The combined data set from the spacecraft and from complementary ground-based observations will be used to construct quantitative models to describe how mass, momentum, and energy from the solar wind are transported across boundaries, stored and energized in the magnetosphere, and subsequently dissipated into the Earth's atmosphere.

The chart on the following pages lists the GGS Initiative investigations, their Principal Investigators, and the institutions supporting them.

NASA is collaborating with the European Space Agency (ESA) in two additional solar-terrestrial missions, SOHO and Cluster. SOHO will investigate the interior dynamics of the Sun that produce the energy flow and magnetic field structure at the base of the solar corona. It will also study the corona to better understand the energy deposit and subsequent acceleration of plasma and particles into the solar wind. Cluster will use four spacecraft to conduct three-dimensional investigations on smaller scale spatial structure and on plasma turbulence throughout the polar and middle magnetosphere as well as in the solar wind.

ESA will provide both the SOHO and Cluster spacecraft while the investigations, launch, mission operations, and network support are shared with NASA. Together, SOHO and Cluster form the ESA Solar Terrestrial Science Program (STSP).

NASA characterizes its contribution to solar-terrestrial missions in the 1990s as the International Solar Terrestrial Physics (ISTP) science initiative, whose aim is to derive the physics of the behavior of the solar-terrestrial system to predict how the Earth's atmosphere will respond to changes in the solar wind.

Investigation	Principal Investigator	Institution
Wind		
Radio and Plasma Waves	J. Bougeret	Paris Observatory
Solar Wind Experiment	K. Ogilvie	Goddard Space Flight Center
Magnetic Fields Investigation	R. Lepping	Goddard Space Flight Center
Energetic Particle Acceleration, Composition, and Transport	T. Von Rosenvinge	Goddard Space Flight Center
Solar Wind Ion Composition Study, the "Mass" Sensor, and Suprathermal Ion Composition Study	G. Gloeckler	University of Maryland
Three-Dimensional Plasma Analyzer	R. Lin	University of California at Berkeley
Transient Gamma Ray Spectrometer	B. Teegarden	Goddard Space Flight Center
Gamma Ray Spectrometer	E. Mazets/T. Cline	Ioffe Institute, Russia/Goddard Space Flight Center
Polar		
Magnetic Fields Experiment	C. Russell	University of California at Los Angeles
Electric Fields Investigation	F. Mozer	University of California at Berkeley
Plasma Waves Investigation	D. Gurnett	University of Iowa
Hot Plasma Analyzer	J. Scudder	Goddard Space Flight Center
Thermal Ion Dynamics Experiment	T. Moore	Marshall Space Flight Center
Toroidal Imaging Mass-Angle Spectrograph	E. Shelley	Lockheed Palo Alto Research Laboratory
Charge and Mass Magnetospheric Ion Composition Experiment	T. Fritz	Los Alamos National Laboratory
Comprehensive Energetic-Particle Pitch-Angle Distribution	B. Blake	Aerospace Corporation
Ultraviolet Imager	M. Torr	Marshall Space Flight Center
Visible Imaging System	L. Frank	University of Iowa
Polar Ionospheric X-Ray Imaging Experiment	W. Imhof	Lockheed Palo Alto Research Laboratory

Investigation	Principal Investigator	Institution
Geotail		
Electric Fields Detector	K. Tsuruda	Institute of Space and Astronautical Science
Magnetic Fields Measurement/Geotail Inboard Magnetometer	S. Kokubun/M. Acuña/ D. Fairfield	Institute of Space and Astronautical Science/ Goddard Space Flight Center
High-Energy Particles	T. Doke	Waseda University
Low-Energy Particles	T. Mukai	Institute of Space and Astronautical Science
Plasma Waves Investigation/Multi-Channel Analyzer	H. Matsumoto/R. Anderson	Kyoto University/University of Iowa
Energetic Particle and Ion Composition	D. Williams	The Johns Hopkins University Applied Physics Laboratory
Comprehensive Plasma Investigation	L. Frank	University of Iowa
Ground-Based		
Canadian Auroral Network for the Origin of Plasmas in Earth's Neighborhood Program Unified Study	G. Rostoker	University of Alberta
Satellite Experiments Simultaneous with Antarctic Measurements	J. Dudeney	British Antarctic Survey
Sondrestrom Radar	J. Kelly	Stanford Research Institute
Dual Auroral Radar Network	R. Greenwald	The Johns Hopkins University Applied Physics Laboratory
Theory and Modeling		
Mission-Oriented Theory	M. Ashour-Abdalla	University of California at Los Angeles
Theory, Modeling, and Simulation Support	D. Papadopoulos	University of Maryland
Theory, Simulation, and Modeling	M. Hudson	Dartmouth College
Modeling of the Atmosphere-Magnetosphere-Ionosphere System	M. Rees	University of Alaska

From the Sun, the Earth receives (1) energetic charged particles that contribute mass and energy to the atmosphere and heat it, (2) momentum that deforms the Earth's magnetic field into a tail, and (3) light that contributes to the heating of the Earth's atmosphere and ionizes particles in the upper atmosphere to create the ionosphere. Both the solar wind and the ionosphere are major source regions for plasma in the geospace around Earth. Geospace also contains two major storage regions for plasma: (1) the geomagnetic tail and (2) the near-Earth plasma sheet and the ring current. These four basic geospace regions are interconnected by a complex network of energy-transporting processes that join them into a working whole.

The GGS Initiative satellites will be positioned to observe these four regions and the processes occurring within them. Their investigations will perform local measurements of the various particle species that compose the plasma and the electric and magnetic fields that control the plasma's behavior and will remotely image the results of particle interaction with the upper atmosphere, giving integral measures of particles raining down.

The solar wind stretches out the solar magnetic field, whose direction relative to Earth's field, in combination with the solar wind velocity, appears to determine the occurrence of interactive coupling between the solar wind and Earth's environment. This electromagnetic coupling determines how much energy is transferred into the magnetosphere. Coupling mechanisms involve complex electromagnetic interactions whose consequences will be studied as the prime mission of the ISTP Program.

Knowledge of the electric and magnetic fields is particularly important in understanding coupling mechanisms. For example, when the solar wind meets the Earth's magnetosphere, the electric field associated with the plasma motion of the solar wind is impressed on the magnetosphere. The electric field of the solar wind controls coupling between the two regions and determines whether particles from the solar wind will enter the magnetosphere. Determining electric fields provides information on the strength of the interaction.

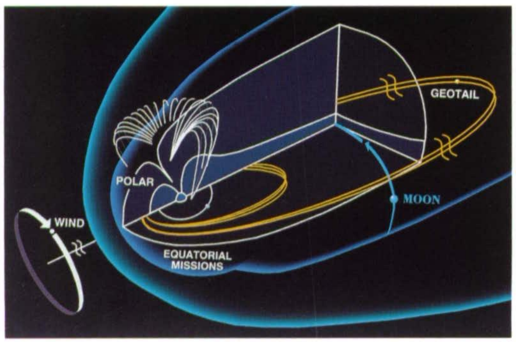
Particle measurements also can be used to deduce coupling mechanisms as well as the topology of field lines and the particles' destination (with the energy they carry), because particles tend to flow along field lines and they have distinguishing characteristics. For example, a particle's charge state can be used to trace its origin from either the Sun or the ionosphere. Because the Sun is so hot, particles originating there tend to be stripped of many electrons, such as iron ions with 15 electrons stripped off or helium with two electrons removed. Particles from Earth's ionosphere, irradiated by the Sun, are weakly ionized with lesser charges, such as oxygen or helium with one electron removed.

Particles also affect coupling by altering the current. For example, the ring current within the Van Allen radiation belts is one of the major storage regions for energy from the interplanetary medium. It contains particles of such high energy that they circulate perpendicularly to the curved magnetic field lines, actually drifting across field lines around Earth's magnetic equator. Because they circulate in a kind of closed (if interrupted) pattern, particles form a current, which is the source of a field. Therefore, these changes in the particles of the ring current alter the current and thus the effective magnetic field that the ring current produces.

Measurements taken by the spacecraft instruments are useful indicators for mapping the flow and exchange of energy in the Earth system to derive a balance sheet of energy entering and leaving geospace. Deducing the components of this energy flow will contribute to the development of a quantitative model of energy exchange on a global scale.

SPACECRAFT

The Geotail spacecraft inaugurated the ISTP Program with its launch by a Delta II rocket from the Cape Canaveral Air Force Station on July 24, 1992. Geotail uses lunar gravitational assists to keep the spacecraft on the nightside of the Earth in its initial distant orbit around the Earth. This orbit has an apogee (farthest point from Earth) of 220 Earth radii and a perigee (closest point to Earth) of approximately 8 Earth radii. Geotail will be repositioned later into a near-Earth elliptical orbit with an apogee of approximately 30 Earth radii. The solar wind draws the Earth's magnetic field into a long tail on the nightside of the Earth and stores energy in the stretched field lines of the magnetotail. During active periods, the tail couples with the near-Earth magnetosphere, sometimes releasing energy stored in the tail and activating auroras in the polar ionosphere. Geotail measures the flow of energy and its transformation in the magnetotail and will help clarify the mechanisms that control the input, transport, storage, release, and conversion of mass, momentum, and energy in the magnetotail.



Orbits of the GGS Initiative spacecraft, with the Geotail orbit in yellow.

INVESTIGATIONS

The following investigations are sponsored by ISAS.

Electric Fields Detector (EFD)—Geotail's measurement of the electric field in the tail is key to developing a theory about the formation of the magnetotail. Electric fields in the near-Earth magnetosphere are closely coupled with the ionospheric electric field. EFD studies the coupling of these fields, especially during substorms, using electric-field antennas sampling at 64 samples per second and an electron beam technique at 2 samples per spin. In addition, the merging of magnetic fields in the plasma sheet generates electric fields that help to accelerate particles, which can be measured by other instruments on board the spacecraft.

Magnetic Fields Measurement (MGF)—Information about the dynamics of the transport of mass, momentum, and energy between the magnetospheric and ionospheric plasma can be inferred from monitoring changes in the magnetic-field configuration in various regions. MGF measurements as rapid as 16 samples per second in the near-Earth tail plasma should provide more information about mechanisms (for example, field-line merging) that transfer energy and trigger substorms. MGF investigates magnetic merging in the magnetotail, which is thought to produce a bubble of plasma, called a plasmoid, that flows down the tail during the active periods. Also, MGF observes the distant tail to determine its magnetic-field structure—whether well ordered or filamentary, for example—and its dynamic changes associated with substorms. MGF contains the Geotail Inboard Magnetometer provided by the United States.

High-Energy Particles (HEP)—Measurements of high-energy particles up to 25 million electronvolts (MeV) for electrons, 35 MeV for protons, and 210 MeV per charge for ions can indicate plasma boundary surfaces and reflect whether magnetic field lines are open or closed. The composition and charge state of energetic particles provide rich information on where particles originate, and different solar events produce different energetic-particle signatures. Small, hot sites in the corona produce samples rich in helium ions, for example. The

origin and acceleration of galactic cosmic rays and their modulation in our galaxy are also being investigated.

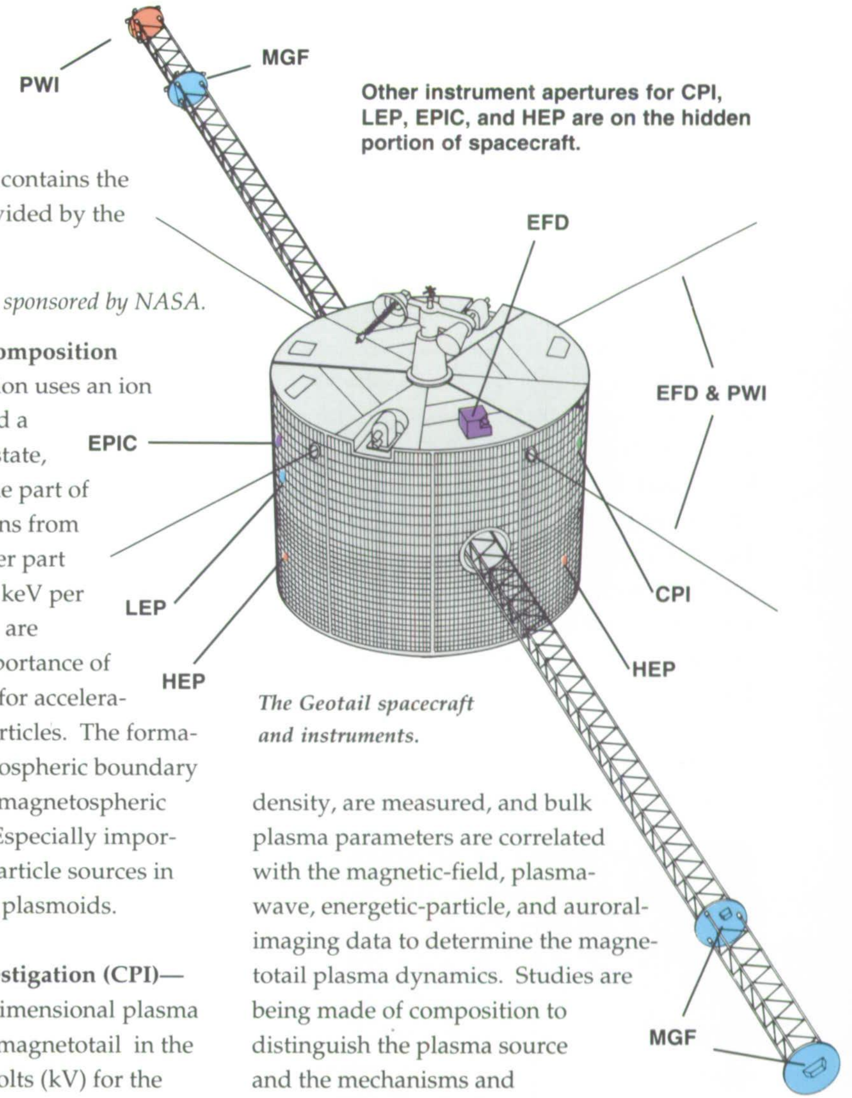
Low-Energy Particles (LEP)—Low-energy electrons from 6 electronvolts (eV) to 36 kiloelectronvolts (keV) and ions from 7 eV to 42 keV per charge are being observed in the magnetotail and in the interplanetary medium to study the nature and dynamics of magnetotail plasmas, analyze the plasma conditions under which particle acceleration takes place, and study plasma circulation and its variability in response to fluctuations in the solar wind and in the interplanetary magnetic field. Particles from Earth's ionosphere are being identified and the entry of plasmas into the magnetosphere from the magnetosheath is being studied to improve our understanding of open versus closed magnetospheres.

Plasma Waves Investigation (PWI)—During Geotail's excursions from the near-Earth to the distant-tail regions, PWI measures plasma waves in the frequency range from 5 hertz (Hz) to 800 kilohertz (kHz) to sample wave phenomena related to plasma dynamics in the different regions on various scales within its range. These phenomena include magnetic-field-line merging, moving plasmoids, and particle acceleration via wave-particle interaction within the magnetotail. PWI contains the Multi-Channel Analyzer provided by the United States.

The following investigations are sponsored by NASA.

Energetic Particle and Ion Composition (EPIC)—The EPIC investigation uses an ion composition spectrometer and a telescope to measure charge state, mass, and energy of ions. One part of the investigation measures ions from 50 keV to 3 MeV, and the other part measures ions from 10 to 230 keV per charge. These measurements are used to study the relative importance of ion sources and mechanisms for acceleration, transport, and loss of particles. The formation and dynamics of magnetospheric boundary layers and their influence on magnetospheric behavior are being studied. Especially important is the determination of particle sources in large-scale structures such as plasmoids.

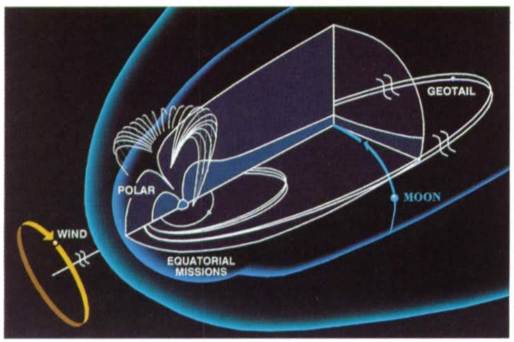
Comprehensive Plasma Investigation (CPI)—CPI obtains complete three-dimensional plasma measurements in the Earth's magnetotail in the range of 1 volt (V) to 50 kilovolts (kV) for the Hot Plasma and Ion Composition Analyzer and 150 V to 7 kV energy per unit charge for the Solar Wind Analyzer. Plasma parameters, including heat flux and field-aligned current density, are measured, and bulk plasma parameters are correlated with the magnetic-field, plasma-wave, energetic-particle, and auroral-imaging data to determine the magnetotail plasma dynamics. Studies are being made of composition to distinguish the plasma source and the mechanisms and efficiency of the coupling of the solar-wind energy (measured by Wind instruments) into the magnetosphere as a function of the upstream solar-wind conditions.



The Geotail spacecraft and instruments.

SPACECRAFT

The Wind spacecraft will be launched by a Delta II rocket from the Cape Canaveral Air Force Station into a figure-eight orbit around the Earth and the Moon on the Sun side of the Earth. The Wind orbit will have an apogee as far as 250 Earth radii and a perigee of at least 5 Earth radii. The satellite will spin at 20 revolutions per minute. From this orbit, Wind will measure properties of the solar-wind plasma before it reaches the Earth and will observe the volume of geospace called the foreshock, where turbulence is produced by particles reflected from the bow shock. Later, Wind will be inserted into a small circular orbit between the Earth and the Sun around the point where their gravity fields are balanced, near 250 Earth radii, to continuously observe the solar wind an hour or so before it intercepts the magnetosphere.



Orbits of the GGS Initiative spacecraft, with the Wind orbit in yellow.

INVESTIGATIONS

Radio and Plasma Waves (Waves)—The Sun and the Earth emit radio waves that affect particles in the interplanetary plasma and carry some of the energy flowing there. The radio and plasma wave instrument will measure the properties of these waves and other wave modes of the plasma over a very wide frequency range. Analyses of these measurements, in coordination with plasma, energetic-particle, and magnetic-field measurements, will further the understanding of these phenomena.

Solar Wind Experiment (SWE)—In this investigation, ions and electrons in the solar wind and the foreshock regions (particles whose energies are in the kiloelectronvolt range) will be measured at a rate of once per minute for ions and 20 times per minute for electrons. From these measurements, the solar-wind velocity, density, temperature, and heat flux can be deduced. Electron and ion velocity distributions should reveal properties of the flowing plasmas and their pivotal role in the transfer of mass, momentum, and energy from the Sun to the Earth. Because the solar wind is an extension of the corona, from which it is accelerated, these measurements also assist in studies of the Sun. Measurements made in the foreshock are important for understanding the structure of the bow shock.

Magnetic Fields Investigation (MFI)—MFI will investigate the structure and fluctuations of the interplanetary magnetic field, which influence the transport of energy and the acceleration of particles in the solar wind. The direction of the magnetic field vector, which MFI will map, is crucial in interactions between the solar wind and the magnetosphere. The magnetometer, which measures the intensity of the magnetic field, has a measurement rate of 44 vectors per second. These fundamental magnetic field measurements are especially important to the interpretation of other data from Wind.

Energetic Particle Acceleration, Composition, and Transport (EPACT)—The EPACT investigation will determine elemental and isotopic abundances for the minor ions making up the solar wind with energies in excess of 20 keV. This direct sampling of solar matter is a way to study events on the solar surface and the incorporation of solar material into the solar wind. Because the solar-wind ions' high charge

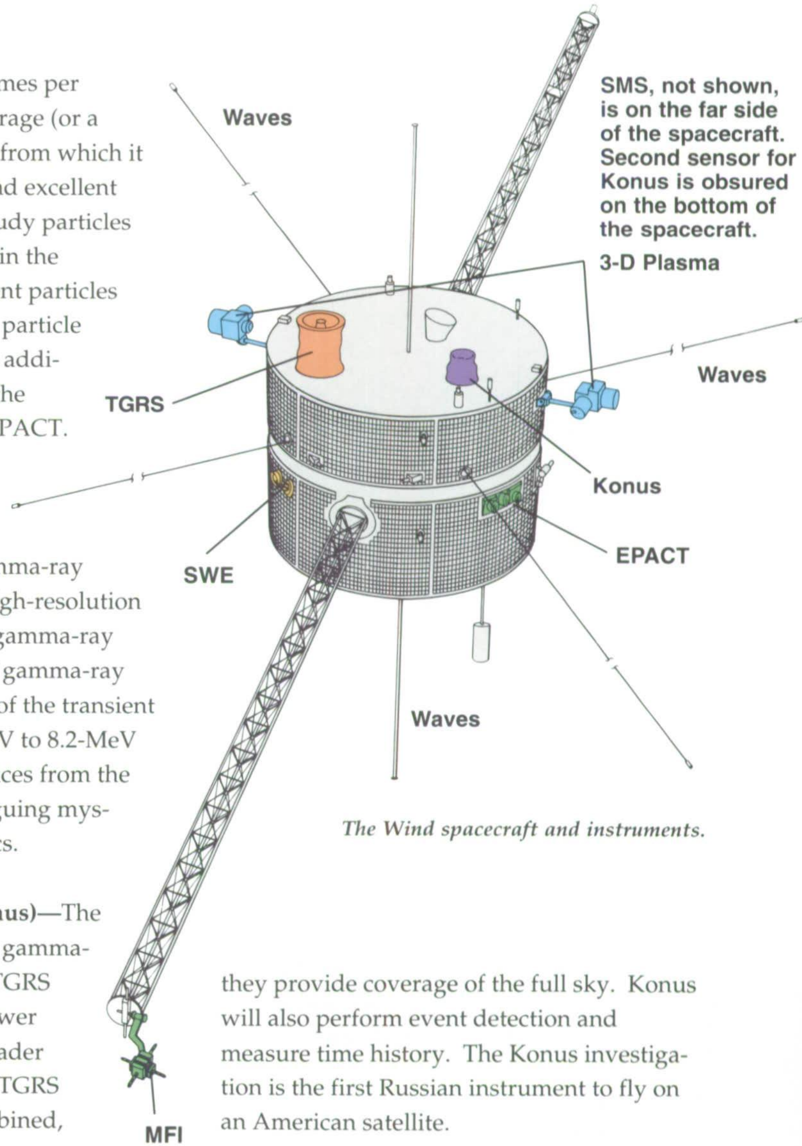
distinguishes them, they can be used as tracers for the transfer and flow of particles from the solar wind in the magnetosphere. EPACT will also provide information on shocks in the interplanetary medium, which accelerate particles from solar-wind energies to several hundred kiloelectronvolts.

Solar Wind Ion Composition Study (SWICS), Mass Sensor, and Suprathermal Ion Composition Study (STICS), combined to form a single investigation called SMS—This investigation will determine the abundance, velocity, spectra, temperature, and thermal speeds of solar-wind ions. These ions and their abundance fluctuations form another diagnostic of events on the solar surface, complementing the EPACT and plasma investigations. One part of the instrument combination will offer sufficient resolution, for the first time at solar-wind energies, to study the isotopes of many elements. This investigation will add to our knowledge of how the solar wind is formed and accelerated from the solar surface into the interplanetary medium.

Three-Dimensional Plasma Analyzer (3-D Plasma)—This investigation will measure ions and electrons with energies above that of the solar wind and into the energetic particle range. It will cover the energy range from 0.03 to 30 keV, measuring at a rate of 20 times per minute, with wide angular coverage (or a wide range of arrival directions from which it can detect ions and electrons) and excellent directional sensitivity. It will study particles upstream of the bow shock and in the foreshock region and the transient particles emitted by the Sun during solar particle events following solar flares. In addition, this instrument will cover the energy gap between SWE and EPACT.

Transient Gamma Ray Spectrometer (TGRS)—
TGRS will observe transient gamma-ray events and will make the first high-resolution spectroscopic survey of cosmic gamma-ray transients and measurements of gamma-ray lines in solar flares. The causes of the transient events, which occur in the 15-keV to 8.2-MeV energy range and at great distances from the Earth, represent one of the intriguing mysteries of present-day astrophysics.

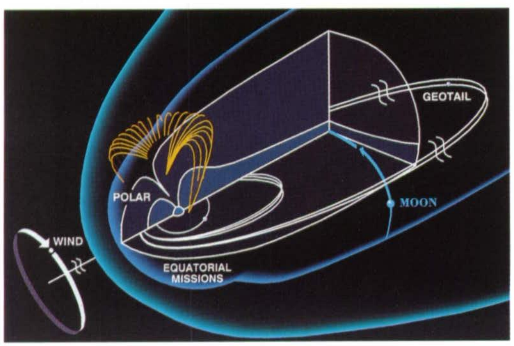
Gamma Ray Spectrometer (Konus)—The objective of Konus is to perform gamma-ray-burst studies similar to the TGRS studies. Although Konus has lower resolution than TGRS, it has broader coverage to complement that of TGRS so that, when their data are combined, they provide coverage of the full sky. Konus will also perform event detection and measure time history. The Konus investigation is the first Russian instrument to fly on an American satellite.



The Wind spacecraft and instruments.

SPACECRAFT

The Polar spacecraft will be launched by a Delta II rocket from the Western Space and Missile Center. Its orbit will be inclined 90 degrees from the Equator with an apogee of 9 Earth radii and a perigee of almost 2 Earth radii. In this orbit, the spacecraft will initially provide measurements of plasma entry and transport in the northern dayside cusp regions at high altitudes and over the southern polar cap at low altitudes as well as global imaging of the northern auroral zone. With time, the orbit will precess so that measurements can be taken at low altitudes in the northern polar cusp and at high altitudes in the southern polar cap with global imaging of the southern auroral zone from high altitude. The main body of the



Orbits of the GGS Initiative spacecraft, with the Polar orbit in yellow.

spacecraft spins at 10 revolutions per minute, while a smaller platform on the spacecraft is despun and can be pointed to maintain the viewing field of certain instruments.

The Polar spacecraft will contain eleven instruments that can be divided into three categories. The first three instruments will observe the local electromagnetic fields in the low-frequency range of the electromagnetic spectrum. Five instruments will measure the particles entwined with these fields and attempt to determine what causes particles trapped along the magnetic field lines to rain down into the atmosphere and light up the sky in brilliant auroras. The three imaging subsystems will document the consequences as these fields and particles affect the Earth's atmosphere below by measuring photons in the visible, ultraviolet, and x-ray wavelengths of the electromagnetic spectrum.

An important feature of the Polar (and Wind) spacecraft is the onboard interconnection of instrumentation for electronic communication. Data sharing among the instruments can be triggered by pattern recognition schemes in sophisticated onboard computers. These interconnections allow efficient handling of high-data-rate acquisition. For example, data on the magnetic field can be communicated to particle instruments for use in their data organization and compression.

As an ensemble, the Polar instruments will provide a comprehensive picture of the magnetized plasma at different energies, mass discrimination, and angular resolution about the magnetic field while simultaneously recording measurements of energy deposited in the atmosphere. This spacecraft is key to the GGS inventory of plasma and energy sources and sinks in the solar-terrestrial system. Variations in solar-wind conditions cause large-scale disturbances in the geomagnetic tail and significant rearrangements of plasmas and currents at auroral altitudes. These large-scale effects, influenced by the converging magnetic field (which is anchored in the Earth's core), cause particle precipitation and extraction in the northern and southern auroral zones. Polar will record these effects and their accompanying emissions of photons in the x-ray, ultraviolet, and optical ranges. Polar's location will allow it also to document ions leaving the atmosphere and subsequently appearing in the solar wind or electrons of solar-wind origin precipitating to auroral altitudes. These measurements will be used to define the geometry of field lines with a spatial resolution down to the smallest scales.

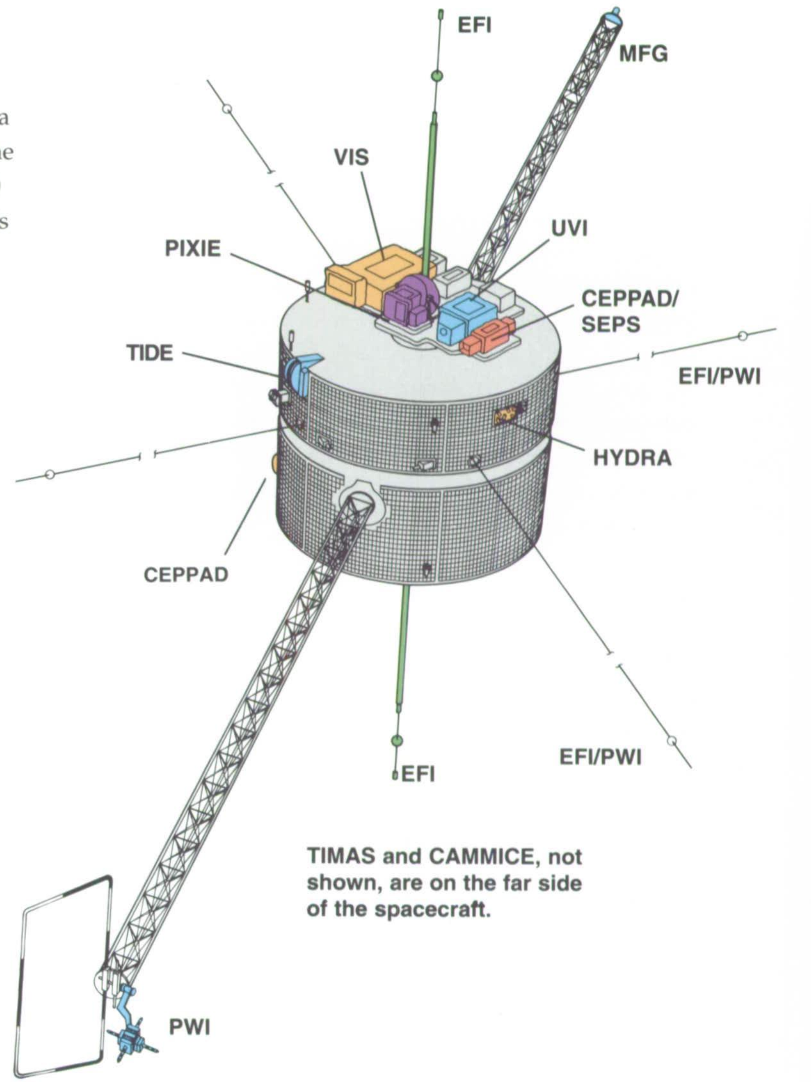
INVESTIGATIONS

The first three investigations will characterize the electromagnetic field of the plasma environment in the vicinity of the Polar spacecraft.

Magnetic Fields Experiment (MFE)—This investigation will use a pair of devices called fluxgate magnetometers to sample the magnetic field in the frequency range from 0 to 50 Hz. Magnetic field strength between 10^{-6} and 0.6 gauss are detectable. The raw measurements will be processed on board at 100 vector samples per second for broadcast to other instruments, thus allowing an economical compression of particle data. Typically, 10 samples per second are transmitted; however, a burst mode allows 100 vector samples per second to be telemetered to the ground. These measurements will be used to study the coupling of the solar wind and the magnetosphere through currents driven in the polar cusp, to determine how energy and momentum are exchanged with the magnetosphere at the cusp-magnetosheath interface, and to investigate the generation of plasma instabilities in the polar magnetosphere.

Electric Fields Investigation (EFI)—This dual-probe instrument will sample the electric field between 0 and 20 kHz. It will sense electric-field strengths between 0.1 and greater than 1,000 millivolts (mV) per meter at a rate of 40 samples per second in the normal mode and more than 1,000 per second in the burst mode. This mode may be commanded to occur simultaneously with Hydra's burst-mode data acquisition. The burst-mode status will be coordinated with the Hydra and TIDE instruments by onboard interconnections. The EFI measurements will be used to infer the electric-field structure of the high-latitude magnetosphere, the cusp, and the plasma mantle. It will also provide direct evidence for field-aligned electrical potential drops, which have been previously inferred to occur.

Plasma Waves Investigation (PWI)—PWI will sample the electric-field noise above the highest EFI frequencies well into the radio band. Magnetic-loop and search coils will be used to sample the magnetic fluctuations above the highest frequencies detectable by MFE to help identify



The Polar spacecraft and instruments.

characteristic modes of plasma behavior. In addition to obtaining the power spectra of plasma emissions, attempts will be made to determine the propagation characteristics associated with these processes. These wave-particle processes mediated by the electromagnetic turbulence are thought to play a central role in momentum transfer in the geospace system, particularly in the boundaries between regions.

The following group of Polar instruments will define the particle populations that accompany the electromagnetic fields identified in the high-latitude magnetosphere.

Hot Plasma Analyzer (Hydra)—The Hydra ensemble of electrostatic analyzers, which compose one-half of Hydra, will filter electrons and ions in energy per unit charge between 1 eV and 30 keV and observe them in 12 directions simultaneously. In addition, a device called a parallel-plate analyzer with a position-sensitive array will image the electrons within and near the magnetic field with 1.5-degree angular resolution in energies between 10 eV and 10 keV. Hydra will measure at a rate of 2 samples per second for complete coverage, although higher frequency energy sweeps or fixed-energy, high-frequency readout are reprogrammable in flight. The low-energy electrons sampled by Hydra will be especially good tracers of the global magnetic topology when compared with simultaneous measurements acquired by SWE in the solar wind. Hydra will also document the electron and ion signatures that accompany geomagnetic substorms, auroral arcs, field-aligned currents, and particle precipitation.

Thermal Ion Dynamics Experiment (TIDE)—TIDE will sample ions extracted from the ionosphere whose mass will be determined by a time-of-flight scheme. Low-energy ions from 0.1 eV per charge to 100 eV per charge will be the focus of TIDE; such ions can be remotely diagnosed by their relatively low ionization state as compared with ions of solar-wind origin. These measurements will be used to evaluate the ionosphere as a source of plasma for the magnetosphere, identify the energization and transport mechanisms for low-energy ions, and study the storage and loss of ionospheric ions.

Toroidal Imaging Mass-Angle Spectrograph (TIMAS)—At higher energies (50 eV to 30 keV), this instrument will sample ions of resolved mass that are either energized ions of ionospheric origin or stored particles of solar-wind origin. Routine data acquisition occurs at a rate of 10 times per minute (once per satellite spin), but it is reprogrammable by ground command. TIMAS will study the properties, location, and morphology of the polar cusp, the principal source region for entry of solar-wind plasma and the hot ionospheric plasma into the magnetosphere. TIMAS data will be used in combination with data from TIDE and from the SWICS instrument on Wind to determine the ultimate origin of mass in the high-latitude magnetosphere.

Charge and Mass Magnetospheric Ion Composition Experiment (CAMMICE) —CAMMICE will determine the composition of major ion constituents in the near-Earth plasma sheet and in the ring current between 6 keV per charge and 60 MeV per ion. For full angular distribution, CAMMICE measures at a rate of 10 samples per minute, or once per spin of Polar. However, the angular resolution is quite high, approaching 0.2 degree. This investigation will add to our understanding of the mechanisms that control the energization, storage, and precipitation of particles in the high-latitude magnetosphere.

Comprehensive Energetic-Particle Pitch-Angle Distribution (CEPPAD)—The CEPPAD investigation uses a variety of techniques to provide detailed energy spectra and angular distributions of energetic particles. Through the Source/Loss Cone Energetic Particle Spectrometer (SEPS) on the despun platform, CEPPAD exploits the pointing of the platform relative to the ambient magnetic field to greatly enhance its angular resolution and measurements of energetic particle precipitation. The sensors, which cover the energy range from 15 keV to 10 MeV, separate protons from electrons. The complete three-dimensional particle distribution is measured every 6 seconds. The CEPPAD investigation will provide quantitative information on the sources, energization, transport, and losses of energetic particles in the magnetosphere. It will also measure the rate of particle precipitation into the Earth's upper atmosphere, part of the energy input that causes auroras and other emissions (which will be remotely sampled by Polar's imaging complement).

The following imaging instruments spatially resolve the Earth in visible light, ultraviolet light, and x rays. The despun platform is particularly suitable for the operation of these instruments.

Ultraviolet Imager (UVI)—UVI will image the dayside and nightside auroras in the vacuum ultraviolet range using five specially designed filters. The detector is an intensified charge-coupled device used in conjunction with a fast reflective optical system to image an 8-degree field of view at a nominal rate of two frames per minute. Improvements over previous imagers will allow the instrument to provide simultaneous global imaging at distances of more than 6 Earth radii. UVI will provide spatial and temporal descriptions of the auroras and images of total particle energy flux, characteristic energy, thermospheric neutral composition, and ionospheric conductances. These images will be used to map the temporal and spatial evolution of electric fields needed for global modeling of the thermosphere at the lower end of the solar-terrestrial chain.

Visible Imaging System (VIS)—VIS will use an image intensifier readout through 12 visible narrowband filters and will produce 5 separate auroral images per minute. Data from VIS and from theory investigations will be used for a quantitative assessment of the dissipation of magnetospheric energy into the auroral ionosphere. A model of the energy flow within the magnetosphere will be developed, using VIS data in three ways: to illustrate the topology of the magnetosphere, to delineate the response of the magnetosphere and the magnetotail to substorms and solar-wind conditions, and to identify the locations and mechanisms for suprathermal charged-particle acceleration.

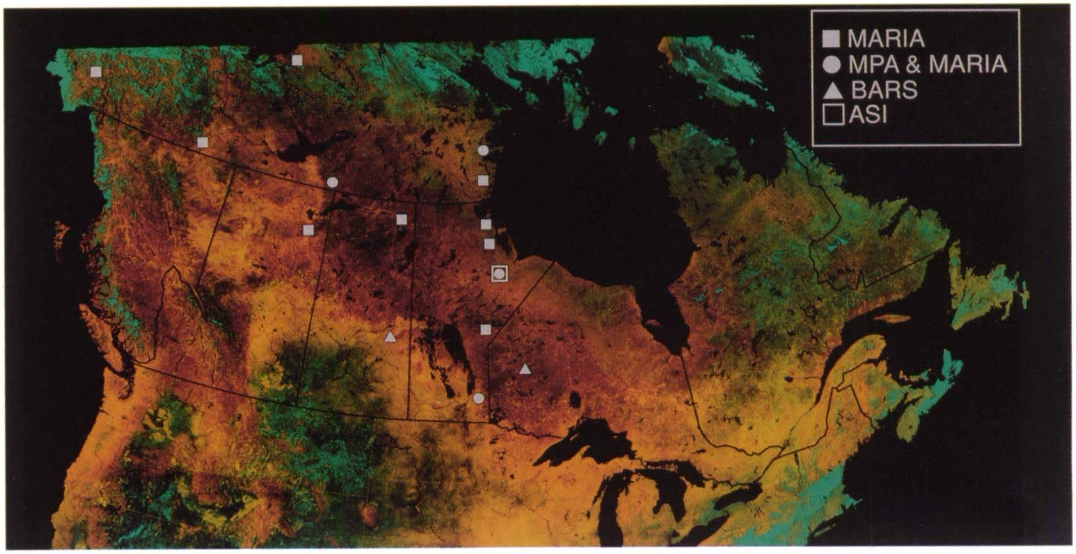
Polar Ionospheric X-Ray Imaging Experiment (PIXIE)—Using a pin-hole camera concept, PIXIE will measure the spatial distribution and temporal variation of x-ray emissions from the Earth's atmosphere. The expected time resolution of images is 60 seconds or better, and the optimal radial distance to obtain the best images is 6 Earth radii. The morphology and spectra of energetic electron precipitation and the effect upon the atmosphere will be derived from the observations. These measurements will be used to derive the total electron energy deposition rate, the energy distribution of the precipitating electrons, and the altitude profile of ionization and electrical conductivity.

Ground-based observations will complement the GGS Initiative space observations by remote sensing of the magnetosphere to provide coverage of regions between spacecraft. While the spacecraft are taking measurements at various points in space, ground-based instruments will be studying phenomena near the Earth in the high-latitude ionosphere. This region is the last link in the chain of interactions through which mass, momentum, and energy are transferred from the Sun to the Earth's atmosphere.

Measurements taken by the ground-based instruments will indicate the effects of processes occurring in the magnetosphere (as observed by the spacecraft) on the Earth's atmosphere. Unlike spacecraft, ground-based instrumentation can also be used to study phenomena in a particular spatial region over an extended period of time so that changes that occur over long time spans can be observed.

The high-latitude ionosphere acts as a boundary to the processes occurring in the inner and outer magnetosphere, the magnetosheath, and even certain regions of interplanetary space. At boundaries between regions, interactive coupling takes place to allow the transfer of mass, momentum, and energy from one region to another. Measurements taken in the high-latitude ionosphere can contribute to our understanding of the role that boundaries and boundary conditions play in determining the global dynamic behavior of the solar-terrestrial system.

Experience has shown that clusters of instruments yield the highest scientific returns. The cluster may be composed of a chain of the same type of instrument (such as a magnetometer, which provides a one- or two-dimensional representation of ionospheric current patterns), or it may contain different instruments that measure the components of the solar-terrestrial system from a single site. Both types of instrument arrangements are included in the four ground-based experiments that support the

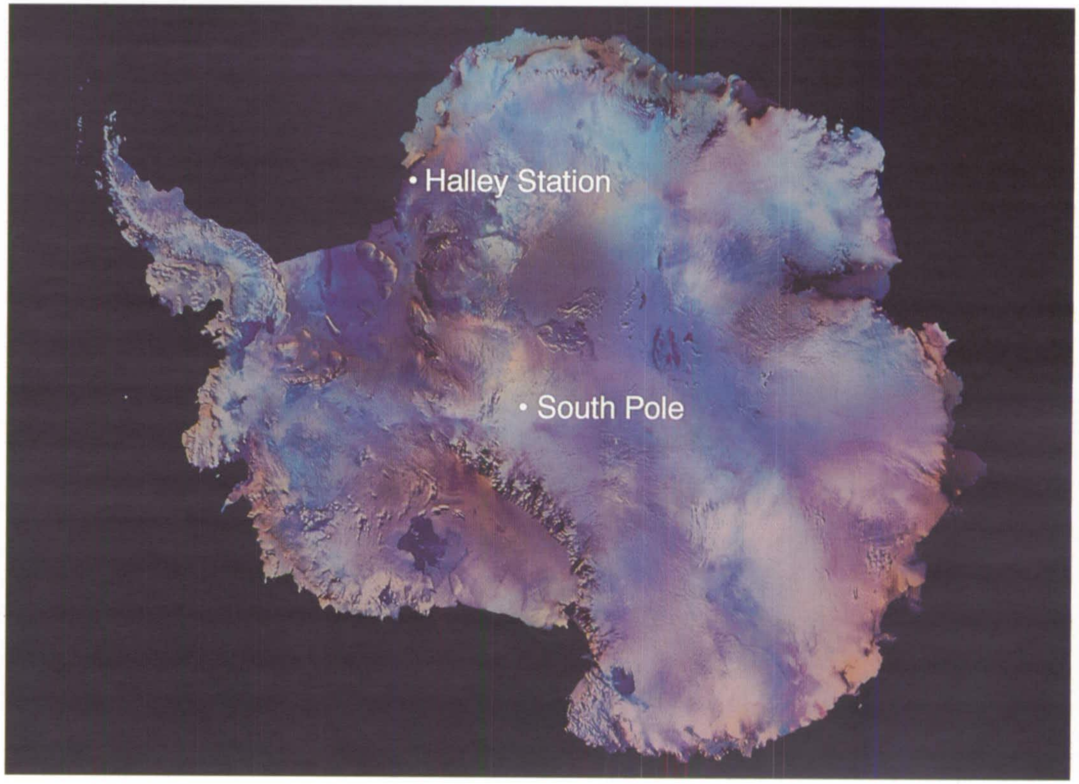


Locations of the CANOPUS sites and their instruments. The Magnetometer and Riometer Array (MARIA) includes magnetometers and relative ionospheric opacity meters (riometers) to measure (1) the intensity of the magnetic field and (2) particle precipitation. The Meridian Photometer Array (MPA) contains optical sensors, which measure in visible light. The All-Sky Imager (ASI) consists of a wide-angle camera that images from horizon to horizon. Finally, the Bistatic Auroral Radar System (BARS) measures horizontal components of the electric field in the auroral ionosphere.

GGS mission: Canadian Auroral Network for the Origin of Plasmas in Earth's Neighborhood Program Unified Study (CANOPUS), Satellite Experiments Simultaneous with Antarctic Measurements (SESAME), Sondrestrom Radar and accompanying instrumentation, and Dual Auroral Radar Network (DARN).

CANOPUS

CANOPUS is an example of the first type of instrument arrangement that supports GGS. Funded by Canada, CANOPUS has been operational since 1989. It provides the following measurements of ionospheric phenomena in the Canadian sector of the northern auroral zone: integral effects of particle precipitation, monitoring of ionospheric currents every 5 seconds, and measurements of horizontal components of the electric fields taken every 20 seconds and with a spatial coverage of more than 160,000 square kilometers and used to infer the field structure. The figure shows the locations of CANOPUS sites and indicates the instruments found at each site.



Location of the SESAME Project at Halley Station, Antarctica. South America is located just beyond the area in the upper left corner of the map.

SESAME

SESAME, located at Halley Station, Antarctica, and operated by the British Antarctic Survey, is an example of the second type of ground-based instrument cluster supporting GGS. The SESAME Project contributes to the following studies: merging and reconnection of the solar-wind field with Earth's magnetic field; mapping of geospace boundaries into the polar ionosphere to determine the relationship of magnetospheric boundaries and ionospheric processes; and ionosphere-thermosphere coupling, using measurements of ion velocity,

The Sondrestrom Radar antenna at Sondre Stromfjord, Greenland.

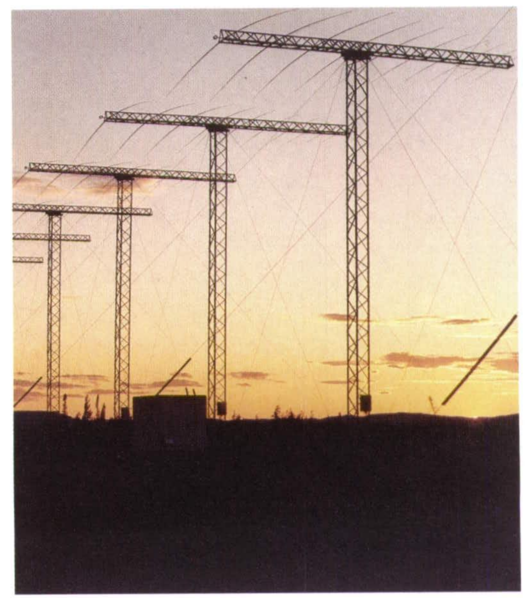
particle flux, ionospheric conductivity, and magnetic-wave intensity and polarization. These measurements reveal the contrasts in the behavior of the ionosphere-magnetosphere system in the Northern and Southern Hemispheres, providing important insights into the mechanisms involved.

Sondrestrom Radar

Like Halley Station, Sondre Stromfjord, Greenland, contains a close clustering of varied but complementary remote-sensing instruments that study the thermosphere, ionosphere, and magnetosphere. Its location beneath the dayside auroral oval makes it an ideal site for studies of ionospheric conditions near the polar cusp, the polar cap, and the poleward edge of the auroral oval. It is particularly useful for identifying the ionospheric manifestations of magnetospheric phenomena and boundaries such as the polar cusp. The Sondrestrom Radar measures several parameters simultaneously over a broad altitude and, because it is steerable, as a function of latitude and longitude. These measurements can be used to derive important ionospheric physical characteristics, including electron density and temperatures; ion composition, temperatures, and drift; plasma velocity; ion-neutral collision frequency; neutral wind; ionospheric conductivity; and electric fields.

DARN

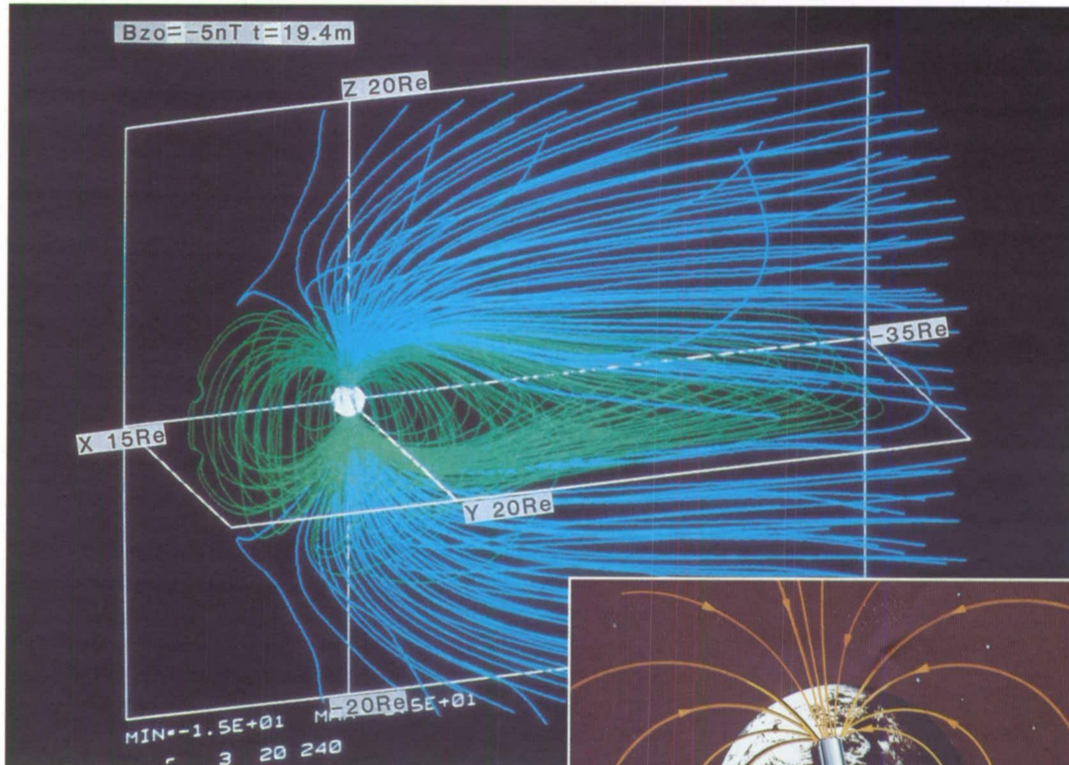
DARN is an international network of radars located in high latitudes and operated by investigators from the United States, Great Britain, Canada, France, Germany, and Finland. These radars operate by sending a signal in the wavelength of the object to be measured and measuring the signal as it is returned or scattered back. Specifically, the DARN radars use backscatter from ionospheric irregularities to study plasma convection and electric fields in the high-latitude ionosphere. DARN data will be used for a wide range of global studies: determination of the global structure and dynamical evolution of high-latitude plasma convection, measurement of magnetohydrodynamic (MHD) waves, measurement of substorm dynamics, observations of atmospheric gravity waves, and studies of high-latitude plasma structure and ionospheric irregularities.

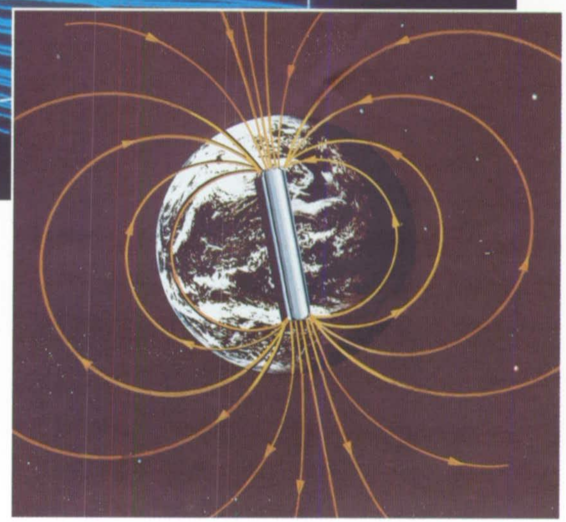


Radar antennas that are part of DARN.

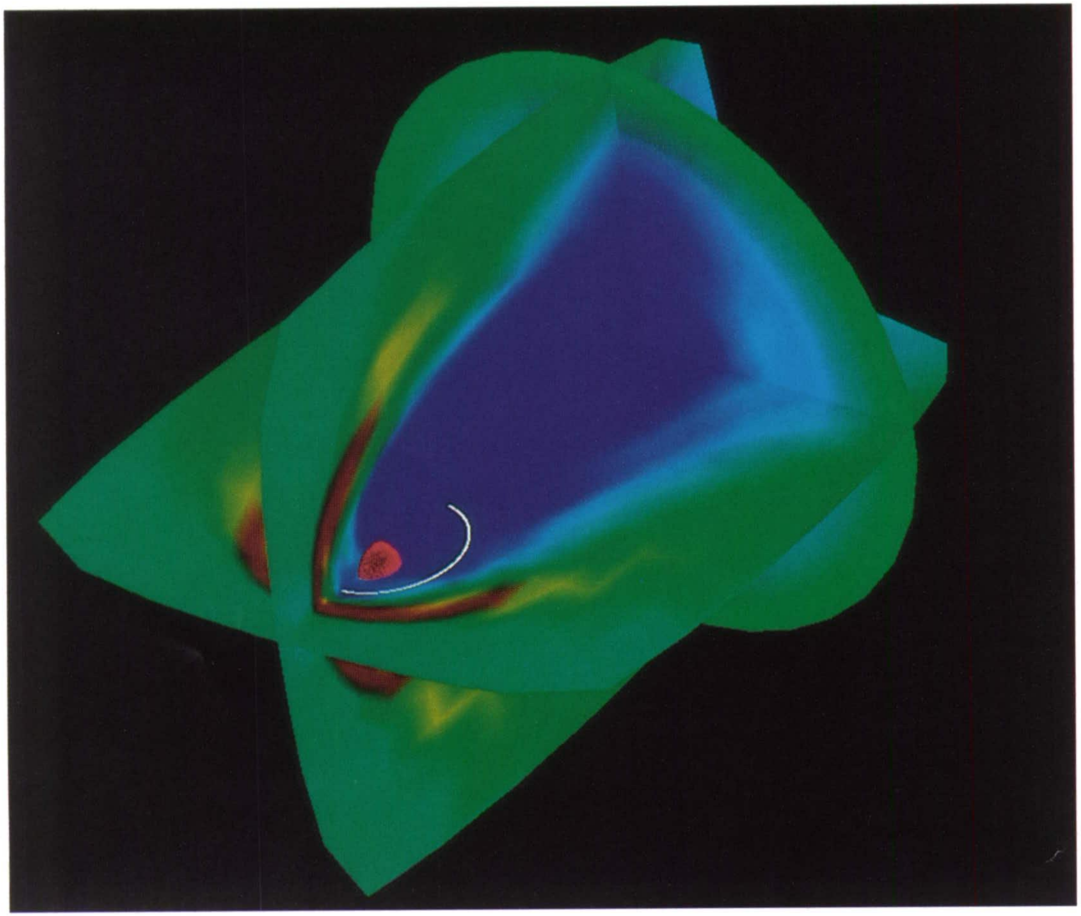
The integration of theory and modeling with spacecraft and ground-based observations represents a new approach to space physics missions that reflects progress in understanding the physical processes that govern solar-terrestrial physics. Theorists play a central role in the ISTP Program—from early planning to spacecraft operations and analysis of the mission data. ISTP theory will focus on the next breakthrough—modeling of the whole solar-terrestrial energy chain on a large scale.

Theoretical tools can model the processes of the magnetosphere within certain scales and under specified conditions. These tools provide a framework for resolving the expected theoretical results of investigations with the actual observations made simultaneously by the spacecraft in different regions of the magnetosphere. Three types of models are being used to help construct a global picture of the magnetosphere. The models are derived from two approaches that describe the plasma dynamics of the magnetosphere: the continuum MHD theory, which describes larger scale fluid dynamics, and the collisionless Vlasov kinetic theory, which describes microscale particle physics. On the largest (or global) scale, MHD models display the flow of mass, momentum, and energy as if the plasmas were a fluid. The theory describes coupling between





If the solar wind did not exist, the Earth's magnetic field lines would be dipolar like those of the bar magnet superimposed on the Earth in the photo at right. However, Earth's magnetic field lines are deformed by the solar wind as shown in the photo above. Coupling between the solar wind and the magnetosphere channels energy to the poles and auroral regions.

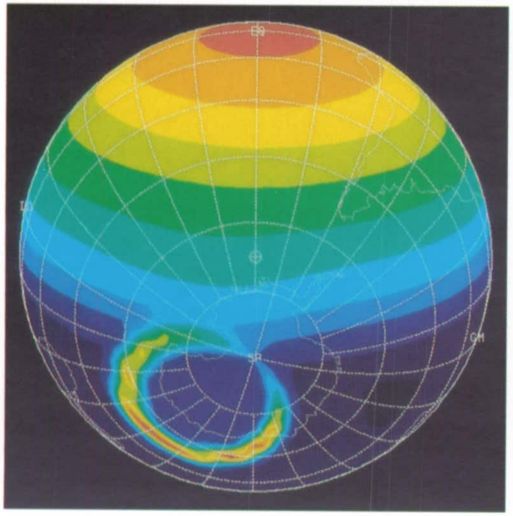


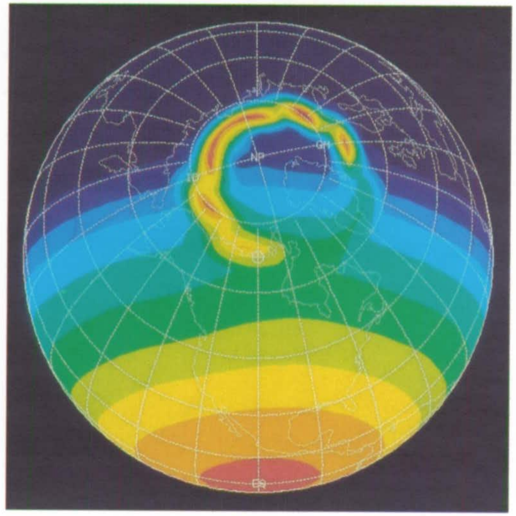
This orthogonal view of a simulated magnetosphere shows the density of particles in plasmas in the magnetosphere. The density is greater at the magnetopause and less in the magnetosphere as shown by the brightness of the colors, red being the most dense, then yellow, green, and blue. This area is covered by the Polar spacecraft's Hydra instrument. The Geotail orbit is shown superimposed on the simulation.

large regions and the cross-field currents that connect them. On the smallest scale, the microscale, kinetic models characterize the motions of individual particles according to their physical properties. On the intermediate scale, or mesoscale, hybrid models combine fluid elements of large-scale structures, such as the solar-wind or magnetotail plasma, with kinetic particle effects.

The influence of microscale processes on global effects (and vice versa) is not yet fully understood. Microscale processes modify the basic properties of the magnetospheric medium, such as its conductivity, which determines coupling between large-scale regions. For example, within each region, kinetic plasma turbulence plays a key role in dissipating the free energy established by the large-scale hydromagnetic configuration. However, this local dissipation can also be influenced by the plasma state in distant regions.

The simulations pictured on these pages illustrate modeling from the global scale of geospace down to the end of the energy chain in the upper atmosphere. The MHD simulations of magnetic field lines (previous page) and of particle density in the magnetosphere (at left) are global, or whole-system, simulations. The other two sets of models show energy deposition from the magnetosphere into the ionosphere and the upper atmosphere,





These simulations produced by global circulation models of the upper atmosphere show the effect of the channeling of energy from the magnetosphere to the poles. The two hemisphere views of the Earth show electron density at the poles and at the Equator. The brighter colors represent higher density. The equatorial density enhancement is due to solar radiation. GGS will be measuring the input from the magnetosphere.

as measured by electron density (above) and temperature and winds (next page). Energy from the magnetosphere enters at the poles in the form of precipitating particles and extreme ultraviolet radiation. This energy penetrates primarily only to the altitudes of the ionosphere and upper atmosphere. Therefore, the models show higher temperatures at the poles than at the Equator. By contrast, visible light penetrates all the way to the Earth's surface and heats the Equator at the lower altitudes more than it heats the poles.

To accommodate this new approach integrating theory with spacecraft and ground-based observations, theory tools must be modified. For example, to aid the investigators interpreting the spacecraft measurements, the theory teams are developing simulation displays that resemble formats used to present satellite wave and particle measurements. Global MHD models with representations (in time) of the magnetosphere will be stored on optical disk. These models can generate dynamic displays of local and global phenomena within the global magnetospheric configuration. The locally observed plasma phenomena can then be linked to the global magnetospheric structure, using these models and theory. Parameterized global models of the magnetosphere will help connect the satellite data taken at various points in geospace, and atmospheric models will complete the connection between phenomena observed in space and the effects seen in the upper atmosphere.

Four Principal Investigator theory teams support the GGS Initiative component of the ISTP Program: University of California at Los Angeles (UCLA), University of Maryland, Dartmouth College, and University of Alaska/ National Center for Atmospheric Research (NCAR).

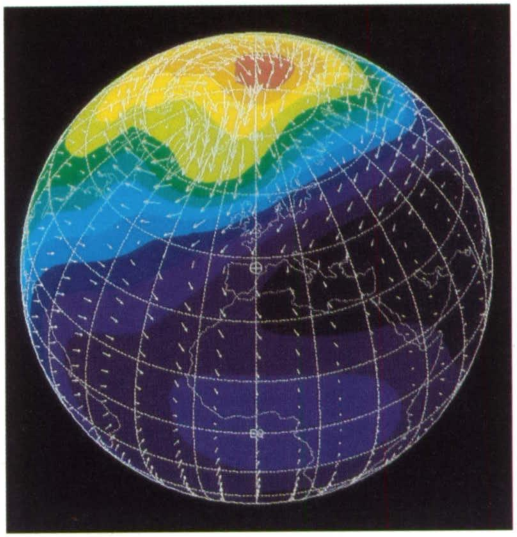
The theory team at UCLA will be doing investigations in all three scales. On the global scale, three-dimensional models will use information obtained by Wind about many properties of the solar wind to predict large-scale dynamics in the magnetosphere. On the mesoscale, the team will be using Tsyganenko's magnetic field model to model the fluid elements of large-scale structures in the magnetotail and add particle calculations of microscale regions. On the microscale, the team will use purely kinetic models of particle and wave interactions to calculate particle distributions and the effect these particle movements have on fields. This team will also produce

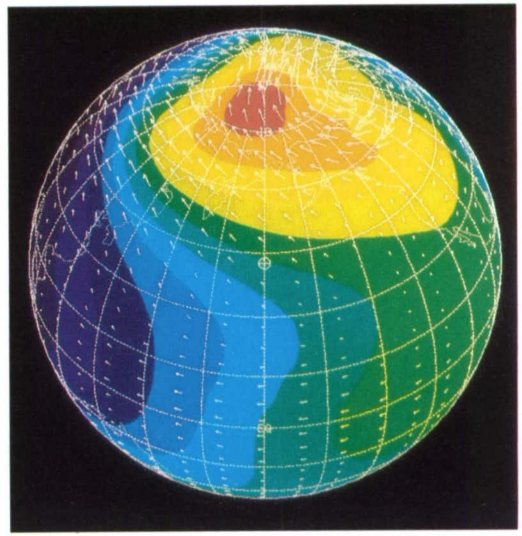
images of the auroral zone to compare with the imaging information obtained from the Polar spacecraft.

The University of Maryland team is investigating global, mesoscale, and microscale processes. The challenge is to tie the local kinetic, wave-particle interactions to the global three-dimensional MHD models, which describe the bulk flows of energy and momentum in large areas. One ambitious method being examined for synthesizing the two models is to incorporate local kinetic codes and dynamic "cells" within the global MHD code to simulate important regions such as the magnetopause. The kinetic codes communicate their boundary conditions into the MHD simulations.

This team will also be developing the next generation of global models by updating simulation codes, using the spacecraft data taken simultaneously from different magnetospheric regions. Multidimensional visualizations that facilitate the interpretation and comparison of global and local simulation data are also being developed to take advantage of advances in high-power workstations.

The Dartmouth College team will rely on comparisons of satellite data to particle simulation data to gain information about energy and mass transfer in microscale and mesoscale processes in the equatorial and auroral regions. In the equatorial region, investigations will





These simulations produced by global circulation models of the upper atmosphere show the actual total energy deposition into the upper atmosphere (from direct solar radiation at the Equator and magnetospheric input at the poles) in terms of temperature. The brighter colors show higher temperatures at the poles in the upper atmosphere in contrast to ground-level temperatures. Arrows indicate wind velocities.

examine the dynamic effects of geomagnetic storms, the loss of ions from the ring current, coupling between the solar wind and upper atmosphere, and the acceleration of particles by stepping up their energy as they cross field lines. In the auroral regions, studies will focus on particles flowing along field lines in an acceleration process that produces the aurora.

The team from the University of Alaska/ NCAR is conducting an investigation called Modeling of the Atmosphere-Magnetosphere-Ionosphere System (MAMI). It focuses on the response of the ionosphere and upper atmosphere to magnetospheric input of energy and momentum carried by particles and fields. Quantities are calculated for atmospheric winds, temperatures, and ion densities and composition. The team studies excitation of atmospheric gases from the precipitation of energetic electrons and derives spectral emission rates from observations by Polar instruments for quantitative studies of auroral images. The quantities calculated for mass, momentum, and energy conducted into the ionosphere are used as input for other models.

Previous missions extended our knowledge of the solar-terrestrial system by discovering and measuring various regions in the Earth's magnetosphere. The ISTP mission will take our knowledge a step further by quantifying the behavior of the electromagnetic forces. Electric and magnetic fields observed by the spacecraft at their different locations will be correlated with observations of ionized particles that travel along the magnetic field lines. The simultaneous data can then be combined with global and localized models to develop our ability to predict the electromagnetic effects of solar events on Earth. To accomplish this objective, the GGS Initiative, as part of ISTP, will use measurements from the spacecraft in different magnetospheric regions and from ground-based observatories, mapping these measurements onto a global grid of the magnetosphere, analyzing the data, and theorizing the cause and effect from this analysis.

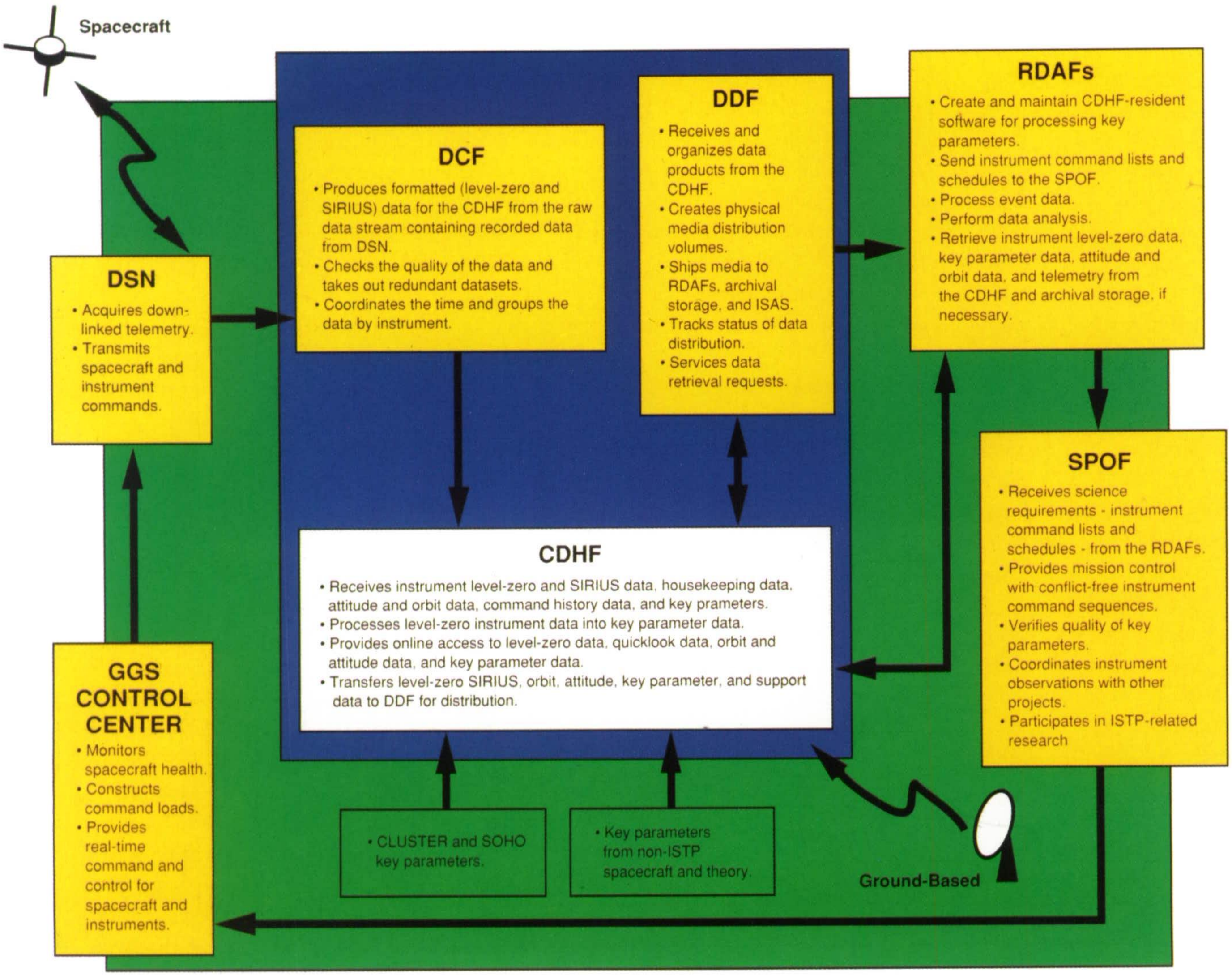
Several NASA and Goddard Space Flight Center facilities will play key roles in the collection and dissemination of the data. The NASA Deep Space Network (DSN) will collect the data from the spacecraft and will command the spacecraft via radio link. At the Goddard Data Capture Facility (DCF), the raw data will be assembled into level-zero files (the first level of processed data). The Goddard Data Distribution Facility (DDF) will be responsible for delivering the data from each investigation to the scientists. So that information can be quickly and easily shared, all the investigators are connected by the NASA Science Internet (NSI) computer network, which has network connections throughout the United States, Japan, and Europe.

The Central Data Handling Facility (CDHF) will be of most interest to the scientific community because the data from the spacecraft and from ground-based observations will be stored, cataloged, and organized there. The CDHF will be the central repository and coordination point for spacecraft and ground-based data, for data from other related missions, and for the models produced by the theory investigators, which will be used to analyze and process data.

One of the CDHF's most important functions will be processing the level-zero spacecraft data into overview or summary data known as "key parameters." These key parameters will serve as a kind of intelligent index or guide to the much larger volume of raw data. Spacecraft data collected over a 24-hour period will be processed into key-parameter data by the CDHF in 6 hours. Once the data has been processed, the CDHF will become the central hub for the large number of investigators.

The detailed analysis of the data will be performed by the investigators using their own computers at their sites. These small investigator facilities, known as Remote Data Analysis Facilities (RDAFs), are all connected electronically to each other and to the CDHF via NSI. From the RDAFs, the investigators will be able to access the key-parameter data at the CDHF. Then, after receiving their instrument data on physical media from DDF, the investigators will use the key parameters as a guide to select intervals of high scientific interest on which to concentrate their analysis.

A project as complex as ISTP requires a continual planning effort so that instruments can be commanded into the proper operating modes when observations of the various spacecraft need to be coordinated in advance to focus on a particular event. This task will be performed by the staff of the Science Planning and Operations Facility (SPOF) in consultation with the Project Scientist and his deputies. The SPOF staff will consist of scientists who are familiar with the overall long-term and short-term goals of the program, as specified by the Science Working Group, and operations personnel who are familiar with the commanding of the spacecraft and the various instruments. The SPOF will be the day-to-day point of contact between the program and the world-wide science team. In addition to performing

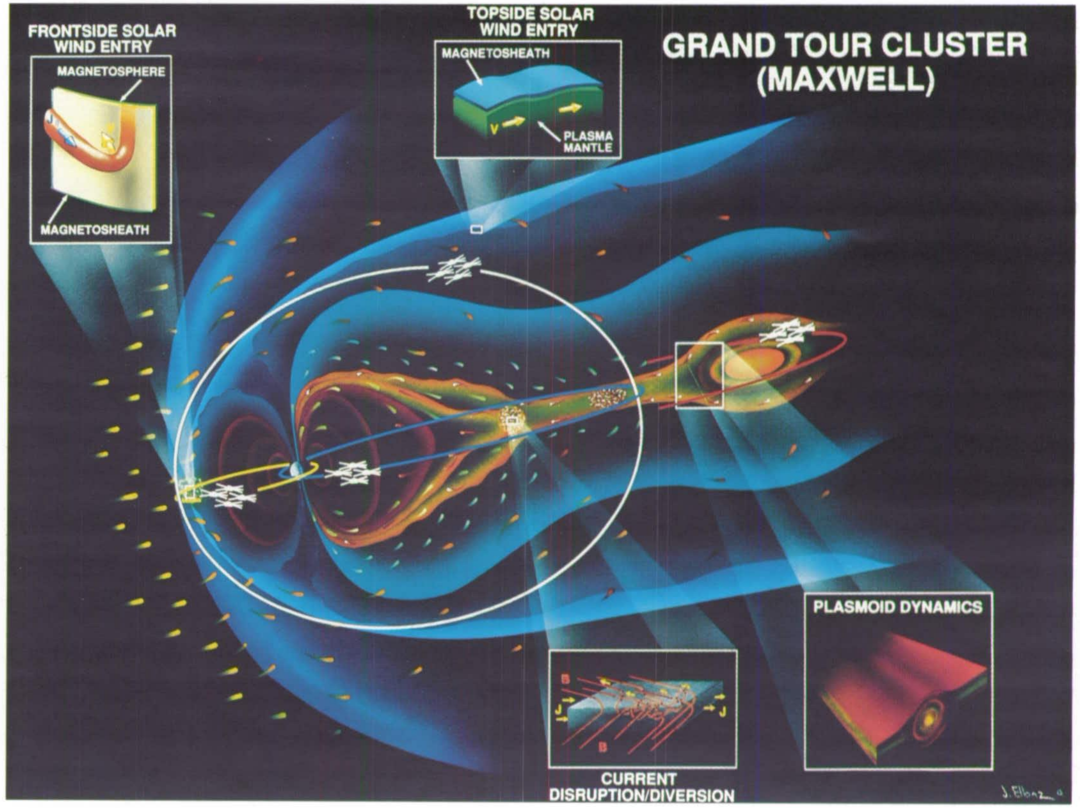


Schematic representation showing the flow of data from the GGS Initiative satellites to the science community for analysis.

this extremely important planning and operations function, the SPOF personnel will be the scientific monitors of the program.

During periods of special interest, the GGS Initiative spacecraft will coordinate their data-gathering efforts with other international missions. The Inter-Agency Consultative Group, representing the space agencies of the United States, Japan, Europe, and Russia, is taking the lead in this coordination, has defined multimission science objectives, and has recommended standardization of data formats and the conduct of specific spacecraft campaigns, each of which will have a definite scientific focus.

ISTP is part of a growing international effort to understand Earth's global space environment. The program, which builds on previous work, will produce the next generation of quantitative pictures of the global physics of the magnetosphere through its interaction of theory and experiment. In the decade preceding ISTP, the development of global three-dimensional MHD simulation codes provided an impetus to study global magnetospheric physics. Likewise, through the development of three-dimensional hybrid and kinetic codes that allow scientists to resolve the physics of mesoscale and microscale magnetospheric processes, ISTP will help set the stage for the next generation of magnetospheric missions. The value of the ISTP Program will be multiplied and extended in contributing to future work. NASA is considering several potential missions that would continue our study of geospace beyond the GGS Initiative part of ISTP.



This illustration of Earth's magnetosphere shows the four spacecraft of the potential Grand Tour Cluster mission in four different orbits, where they would sense magnetospheric fields, plasmas, and energetic particles.

Grand Tour Cluster

The potential Grand Tour Cluster mission represents a natural extension of ISTP and a new frontier. Once ISTP provides the first global study of the transfer of energy into and within the magnetosphere, the next logical step is to understand the nature of the physical processes that underlie the transfer of energy between various regions on the microscale and mesoscale. Grand Tour Cluster would study these smaller scale processes and explore the relation of global dynamics to local processes.

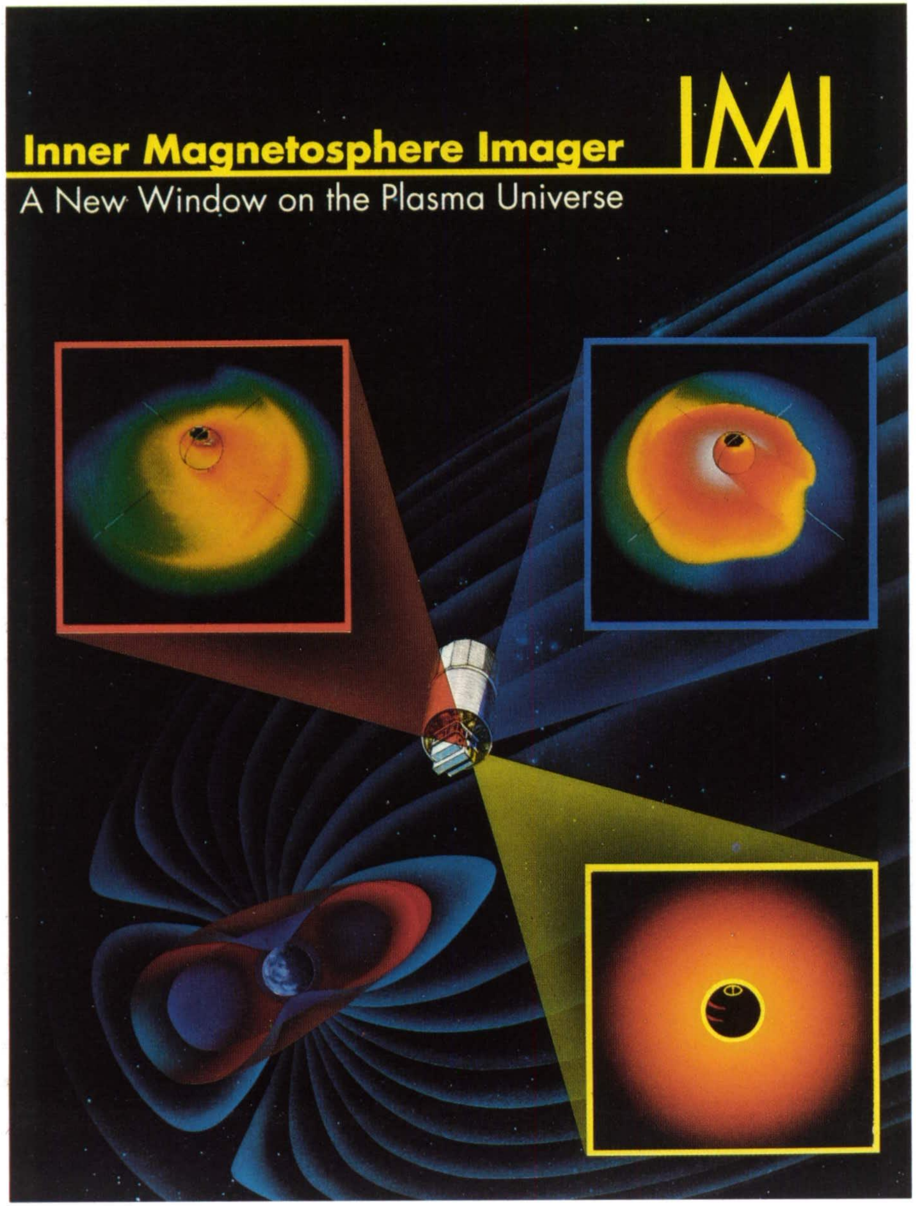
Grand Tour Cluster would consist of four fully instrumented satellites, which would allow three-dimensional sensing of the magnetosphere by means of a number of orbits made possible by lunar flybys. The initial orbits would be near equatorial and would explore the magnetopause, the near-Earth reconnection region, and the near and distant magnetotail. The final orbit would be polar and would skim the dayside magnetopause. A major focus would be to understand the detailed dynamics of magnetospheric boundary layers.

Inner Magnetosphere Imager (IMI)

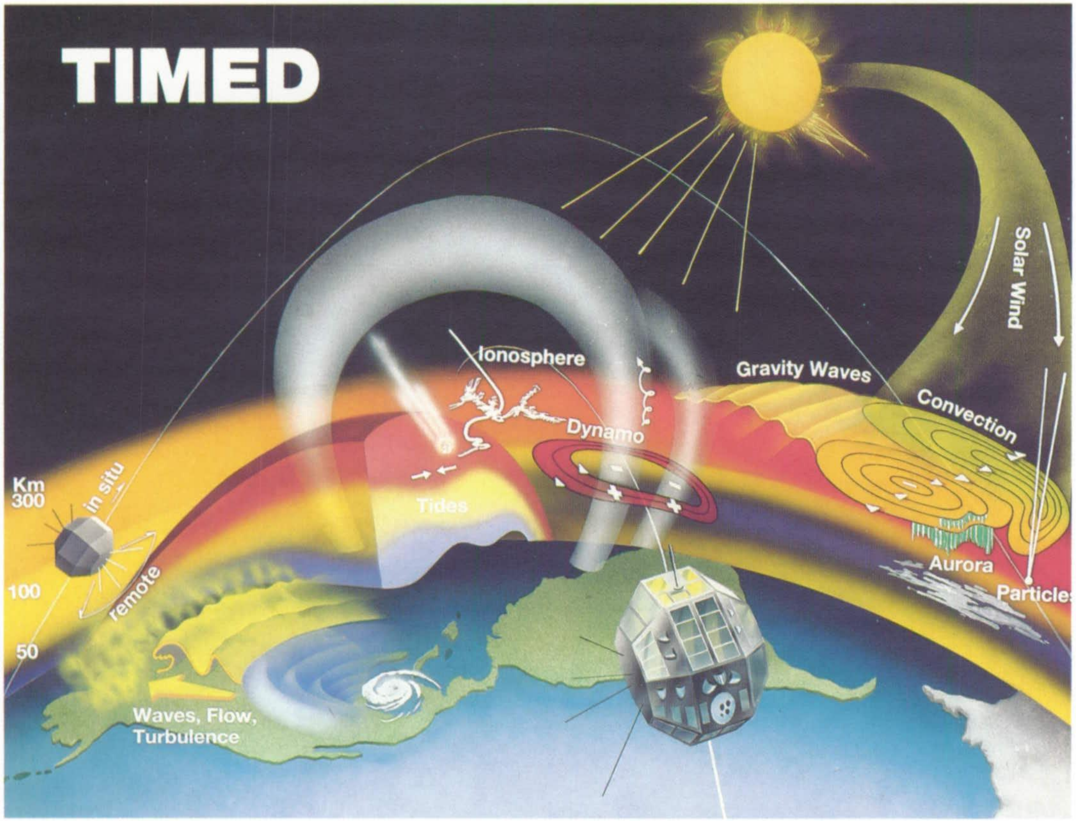
The potential Inner Magnetosphere Imager (IMI) mission would extend the imaging performed by the Polar spacecraft. It would use new techniques for imaging energetic neutral atoms, photons, and charged particles to remotely sense the ring current, plasmasphere, plasma sheet, and auroral regions. In combination with Grand Tour Cluster mission data, IMI data would provide a new perspective on the magnetosphere global system that would help reveal how local processes determine global dynamics.

Thermosphere-Ionosphere-Mesosphere Energetics and Dynamics (TIMED)

Complementing data collected from ISTP, the potential TIMED mission would provide the first comprehensive space-borne investigations of physical and chemical processes in the terrestrial mesosphere and lower thermosphere-ionosphere between 60 and 180 kilometers. This region is a crossroads, or transition region, in the flow of mass, momentum, and energy through the coupled atmosphere-ionosphere-magnetosphere system—where atmospheric temperatures and thermal gradients reach extreme values, turbulent flow changes to diffusive molecular flow, the composition



The potential Inner Magnetospheric Imager (IMI) mission would examine the components of the Earth's magnetosphere by measuring (clockwise from upper left) energetic neutral atoms, ionized helium, and ultraviolet radiation to image, respectively, the ring current and inner plasmasheet, the plasmasphere, and the Earth's corona.



The TIMED mission would characterize composition, energetics, radiation, chemistry, and dynamics of the Earth's mesosphere and lower ionosphere.

changes from molecular to atomic, complex photochemical and electrodynamic processes become predominant, and these combined effects challenge theoretical description. TIMED would provide new understanding of this region, which is poorly understood because of its inherent complexity and the difficulty of measuring at these altitudes that are too high for balloons and too low for long-lived satellites without onboard propulsion.

EPILOG

The GGS Initiative and the larger ISTP Program build on the discoveries of the past, the technologies of today, and the skills of a worldwide scientific community to achieve the first global study of the transfer of mass, momentum, and energy within the solar-terrestrial system. This global study requires observation of the interacting processes that determine the behavior of the system from various points within the system. Thus, each element of the study—spacecraft and ground-based observations and theoretical investigations—plays an important role in defining the various links in the chain of energy transport. As the ISTP Program contributes to our understanding of the causes and effects of the electromagnetic forces that link the Sun and Earth, it will give us new insight into how these forces affect life on Earth.

NASA
Space Physics Division

ACKNOWLEDGMENTS

Without the support of the late Dr. Stanley Dean Shawhan, former head of NASA's Space Physics Division, the ISTP Program would not have become a reality. Dr. Shawhan worked tirelessly in support of the ISTP Program, bringing the science community together to define the science and mission objectives, promoting the program on its scientific merits, and coordinating with international agencies to enhance the scientific return. At the same time, he also was instrumental in establishing a solid mission plan and ongoing program for the Space Physics Division and in building up a strong and vital space science community. He gave the solar-terrestrial science community its current opportunities and laid the foundation for its future. We suffered a great loss by his sudden death on June 21, 1990, but we are committed to carrying on the legacy he left us.

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